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[*Continued on page (III) of Cover.*

MODERN FACTORS AFFECTING ELECTRICITY COSTS AND CHARGES

By J. A. SUMNER, Member.

(*Paper first received* 17*th November*, 1936, *in amended form* 19*th February*, 1937, *and in final form* 31*st August*, 1937; *read before* THE INSTITUTION 11*th March*, *before the* NORTH MIDLAND CENTRE 16*th March*, *before the* SCOTTISH CENTRE 23*rd March*, *before the* SOUTH MIDLAND CENTRE 5*th April*, *before the* NORTH-EASTERN CENTRE 12*th April*, *before the* NORTHERN IRELAND SUB-CENTRE 20*th April*, *and before the* IRISH CENTRE 22*nd April*, 1937.)

SUMMARY

The paper contains a brief review of the thesis presented in 1933 by Mr. Kennedy and Miss Noakes in their paper before The Institution.* These authors concluded that the efficiency of electricity distribution had not improved appreciably during the period 1921–31, and their hypothesis has been accepted in this paper, which consists of a review of modern factors which may be contributing to the lack of increase in the efficiency of distribution.

A brief comparison is made between rural and urban areas and it is concluded that rural areas quickly become remunerative and that they are not likely to have affected the efficiency of the supply industry as a whole. The rate of increase of domestic consumption is analysed for the whole country and it is shown that the average consumption per consumer using electricity for lighting, heating, and cooking, has not increased during the period 1927–35 and that it may have actually decreased during that period, owing to the connection of large numbers of domestic consumers who use only a small quantity of electricity for the minimum purposes, and who are not subsequently increasing their annual consumption.

In order to examine the causes of this lack of development in domestic supplies an analysis is made of the average charges of each undertaking for domestic and power purposes, and the relationship between charges and consumption is also considered. The differentiation between the charges for power and domestic supplies is shown to be irrational if domestic development is envisaged on broad and progressive lines, and it is suggested that domestic supplies may be subsidizing power supplies in many instances.

Finally, the factors mentioned above are shown to be likely to affect seriously the trend of supply development in the immediate future, and the conclusion is reached that the very necessary expansion of development must be controlled and directed in a more co-ordinated manner. It is suggested that the expansion of demand must be preceded by a reduction of charges for domestic supply and a halt in the downward trend of charges for power. The alteration in charges must be accompanied by a greater unification of tariffs and charges which may ultimately be achieved by voluntary arrangements between undertakings but which can only be achieved quickly by means of a single executive authority which would have the exclusive right to direct and initiate the unification of tariffs and charges.

Three reasons are advanced in the paper to account for the mal-development of the domestic supplies, viz.:—

(1) Prices for domestic supply are generally too high to permit of the extensive use of electricity, and reductions in price tend to follow an increased demand, instead of preceding it. As a result the domestic load continues to be restricted, the fixed charges per unit sold remain high, and a condition of expanding demand with consequent falling costs becomes impossible of achievement. This is particularly true for undertakings supplying less than 10 million units per annum.

(2) Electricity for power purposes is sold, in many cases, at charges which are unremunerative and which are considerably below the equivalent cost of production by private plant. The effect of this is to place on domestic charges a burden which prohibits the domestic load from increasing to the point at which its inherently high diversity makes it profitable. This applies chiefly in the case of the larger undertakings.

(3) The absence of a unified tariff basis and a unified scale of charges for electricity causes anomalies and inequities which have a psychological effect in deterring consumption.

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* *Journal I.E.E.*, 1933, vol. 73, p. 97.

FACTORS INFLUENCING DOMESTIC SUPPLIES

Decline in Average Consumption for Domestic Use.

Table 1 shows the number of units sold for lighting, heating, and cooking, and the total number of consumers, since the year 1927–28. The data given in cols. 2 to 6 are obtained from the "Engineering and Financial Statistics" which are issued by the Electricity Commissioners. The lighting, heating, and cooking load is referred to subsequently as the domestic load, as the proportion used for shop lighting and similar uses is not given in the returns. Similarly, the division of consumers between the domestic and power loads is not available, but an indication of the position is given in col. 9 of Table 1. This estimate should be considered in conjunction with a former estimate of domestic consumers made in 1932.* The number of domestic consumers was then estimated for 1930–31 as 82 per cent of the total, or 3·3 millions, leaving approximately 710 000 power consumers, and giving an average annual consumption of 835 units for domestic purposes. The increase in consumers since that date has been largely in domestic consumers, and an approximate estimate of the nature of the increase may be obtained by assuming that the average consumption of power consumers has not increased since 1930–31. This estimate would indicate that the number of power consumers has increased by 255 000, and we have a condition for domestic consumption which is shown in cols. 9 and 10 of Table 1. It is admittedly difficult to arrive at a definite conclusion in the absence of knowledge of the actual number of consumers of each class, but the increases shown in cols. 7 and 8 and the assumptions made from cols. 9 and 10 lead to the conclusion that the average annual consumption per domestic consumer has not increased since 1930–31 and may have actually decreased.

Table 1

VARIATION IN AVERAGE ANNUAL CONSUMPTION OF DOMESTIC CONSUMERS

Year	Units sold for:—		Total consumers (all purposes)	Average revenue obtained per unit sold		Increases in combined lighting, heating, and cooking load, and in consumers, shown as percentage increase on 1927–28		Approximate estimate of consumers and average consumption for lighting, heating, and cooking	
	Combined lighting, heating, and cooking	Power		Combined heating, lighting, and cooking	Power	In units	In total consumers	Domestic consumers	Average domestic consumption
1	2	3	4	5	6	7	8	9	10
	millions	millions	millions	pence	pence	per cent	per cent	millions	kWh
1927–28	1 708	4 537	2·6	3·39	0·94	—	—		
1928–29	2 036	4 926	2·99	3·05	0·86	19	15		
1929–30	2 344	5 408	3·47	2·86	0·82	37	33		
1930–31	2 744	5 371	4·01	2·67	0·81	60	54	3·3	835
1931–32	3 071	5 435	4·65	2·54	0·79	79	79	3·93	785
1932–33	3 469	5 693	5·37	2·41	0·77	102	106	4·62	752
1933–34	3 916	6 392	6·11	2·28	0·73	130	135	5·27	745
1934–35	4 535	7 285	6·90	2·13	0·69	164	166	5·98	765
1935–36	5 505	8 250	7·70	1·92	0·66	223	197	6·60	830

It has to be considered that a normal healthy condition of consumption presupposes a gradual increase each year in the consumption of each connected consumer. If the hypothesis mentioned later of an annual consumption averaging 2 000 units per consumer is adopted, and it is reasonably assumed that a consumer should increase his consumption at such a rate as to permit this average consumption being reached in 5 years, the total annual domestic consumption actually achieved for 1934–35 should have been achieved if no further consumers had been connected since approximately 1931. There has, of course, been an increase in the consumption of many of the consumers who were connected in 1931, as will be seen from the consistent annual reduction in the average revenue received per unit sold (col. 5, Table 1), but such increases are more than negatived by the low consumption of many of the consumers connected since that time.

The chief feature which is emphasized as a result of the data shown in Table 1 is that a knowledge of the *total annual increase* in consumption does not give in itself any measure as to the progress which is being made, and an accurate knowledge of the increased capital cost of providing mains, services, etc., must be available, as well as the number and characteristics of the new consumers; it would be of use if these data could be obtained and published by the Electricity Commissioners. If the increased annual consumption is provided by a large number of consumers whose contribution to revenue is below the average, the new capital required to provide the supply may prove to be unremunerative.

The decline in the average annual consumption per domestic consumer indicates clearly that a large proportion of the domestic consumers connected in recent years have a very low annual consumption. This is confirmed by data from a large undertaking in this country, figures for a 10-year period being:—

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* *Journal I.E.E.*, 1933, vol. 73, p. 108 (estimate of 82 per cent domestic consumers in 1932).

Increase in number of domestic consumers:—400 per cent
Decrease in average consumption:—30 per cent

The decrease in consumption, for this particular undertaking, is due in part to the connection of a large number of prepayment consumers (of a type who not so many years ago would not have been considered as possible purchasers of electricity) obtained under an assisted wiring scheme, and in part to the development of rural areas.

Table 2

Group number	Size of undertaking in group (annual sales of units)	Number of undertakings in group	Total consumers per group	Units sold per group		Average revenue obtained per unit sold		Averaged* annual consumption per domestic consumer in group	Annual income per estimated domestic consumer	Total units sold per £ of distribution capital
				Domestic	Power	Domestic	Power			
1	2	3	4	5	6	7	8	9	10	11
	millions			millions	millions	pence	pence	units	£	kWh/£
1	0 to 0·1	25	7 060	1·5	0·2	7·6	3·3	212·7	6·74	8
2	0·1 to 0·2	27	13 280	3·3	0·9	5·16	2·5	248·5	5·35	15
3	0·2 to 0·3	38	27 800	7·4	2·0	6·0	2·2	266·5	6·67	17
4	0·3 to 0·4	19	19 640	5·4	1·2	3·9	2·0	275·0	4·475	15
5	0·4 to 0·5	19	22 820	7·0	1·2	4·5	2·3	307·0	5·76	17
6	0·5 to 0·75	29	38 900	13·3	4·4	4·3	2·3	342·0	6·13	18
7	0·75 to 1·0	27	46 250	16·9	6·4	3·7	1·9	366·0	5·64	19
8	1·0 to 1·5	46	118 600	50·2	17·6	3·6	2·8	423·0	6·34	22
9	1·5 to 2·0	25	60 600	24·1	18·3	3·5	1·4	398·0	5·80	18
10	2·0 to 3·0	42	142 200	68·0	32·3	3·2	1·4	478·0	6·36	27
11	3·0 to 5·0	34	187 400	85·0	60·0	2·6	1·0	454·0	4·92	33
12	5·0 to 7·5	29	208 800	64·0	108·0	5·0	1·0	307·0	6·40	24
13	7·5 to 10·0	27	271 000	127·0	89·0	2·2	0·8	469·0	4·30	28
14	10·0 to 17·5	42	468 500	325·0	254·0	2·2	0·9	694·0	6·36	39
15	17·5 to 25·0	24	287 500	199·0	267·0	2·5	0·76	692·0	7·21	41
16	25·0 to 37·5	33	643 000	519·0	720·0	2·7	0·68	808·0	9·1	72
17	37·5 to 50·0	15	342 000	339·0	356·0	2·1	0·78	991·0	8·67	53
18	50·0 to 100	21	833 000	721·0	1 025·0	1·9	0·72	868·0	6·77	55
19	100 and over	27	1 868 000	1 511·0	3 745·0	2·0	0·61	810·0	6·74	60

* An arbitrary division of total consumers has been made as follows:—

For undertakings with annual sales less than 5 million units—5 per cent power consumers and 95 per cent domestic consumers.
For undertakings with annual sales above 5 million units—10 per cent power consumers and 90 per cent domestic consumers.

The analysis includes all authorized undertakings for which data are given in the Electricity Commissioners' Returns for 1934–35.

In a paper published in 1936,* which gave statistics relating to a large American supply undertaking, it was stated that "of 535 601 consumers of the Philadelphia Electrical Co. of America, 53 per cent of those consumers do not pay an annual sum covering the operating cost to serve them plus the return permitted by public service law on the facilities allocated to their service; 14 per cent of the consumers do not even pay their operating costs."

A very complete analysis of the cost of supplying small domestic consumers in England was provided by Messrs. Woodward and Carne* in 1932. The portion of their analysis which relates to domestic consumers has been reproduced in an Appendix.

Investigations into the exact costs of providing these consumers with supply should be diverted, in the view of the author, into an experimental examination of the maximum amount of electricity that they can afford to use (see E.D.A. Publication No. 1288, September, 1935) and then, by bold steps in charges, to encouraging their consumption. The extending use of 2-part tariff meters is producing results which are of interest in connection with the problem of the "small consumer."

An analysis has been made for each supply undertaking detailed in the Electricity Commissioners' Returns (1934–35) with a view, primarily, to determining the number of consumers with low annual consumption. The average charge per unit made for domestic supplies was ascertained for each undertaking, and also the average annual domestic consumption, the latter being based upon an estimated proportion of power to domestic consumers. The results for each undertaking were then summarized by forming groups of undertakings in order of size, so as to give the results shown in Table 2. A more detailed analysis is presented in Table 3. The

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* Supplement to the *I.M.E.A. Journal*, January, 1936.

* *Journal I.E.E.*, 1932, vol. 71, p. 852.

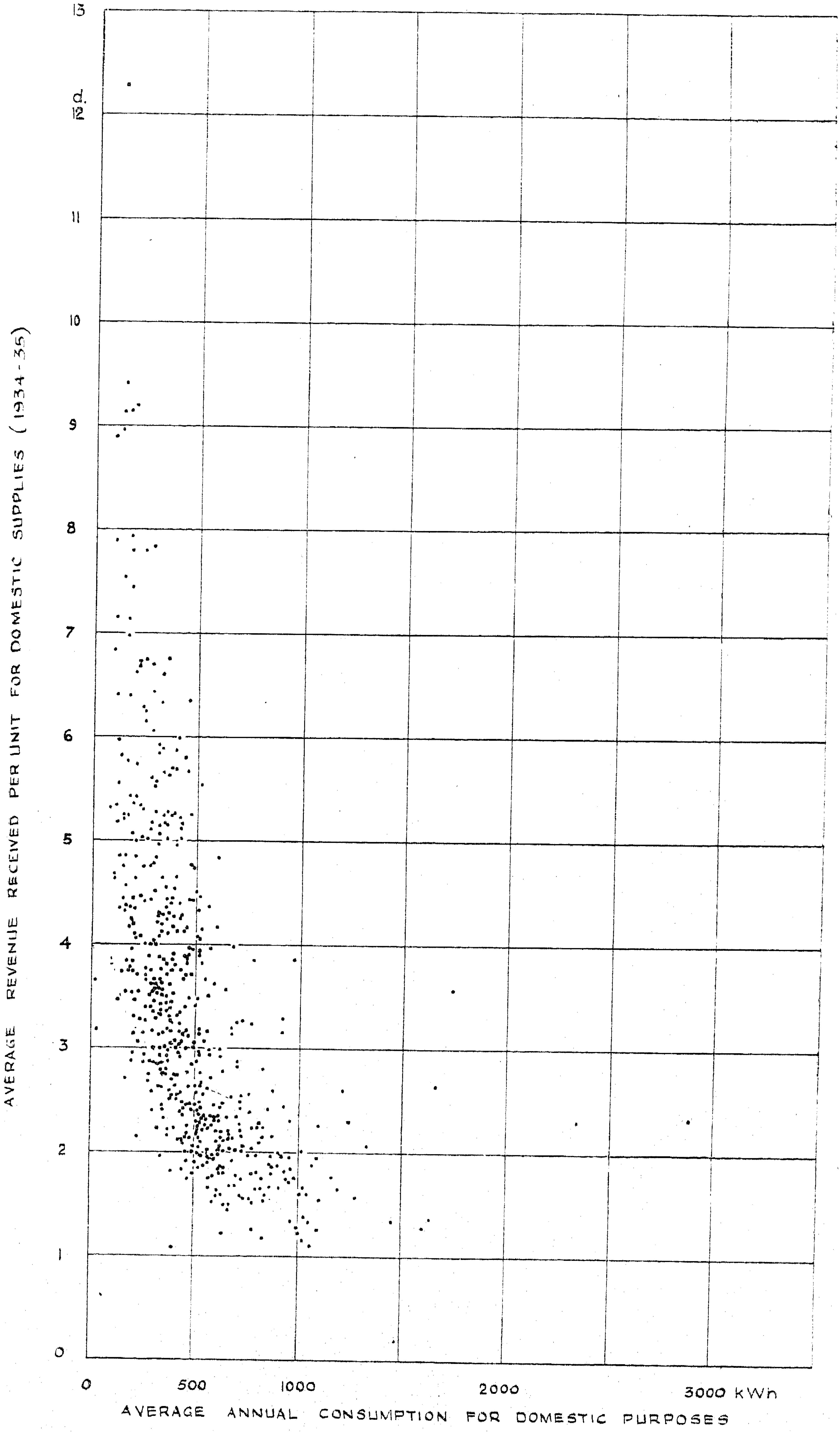

Fig. 1.—Average price received per unit for domestic purposes for 576 undertakings (1934–35).

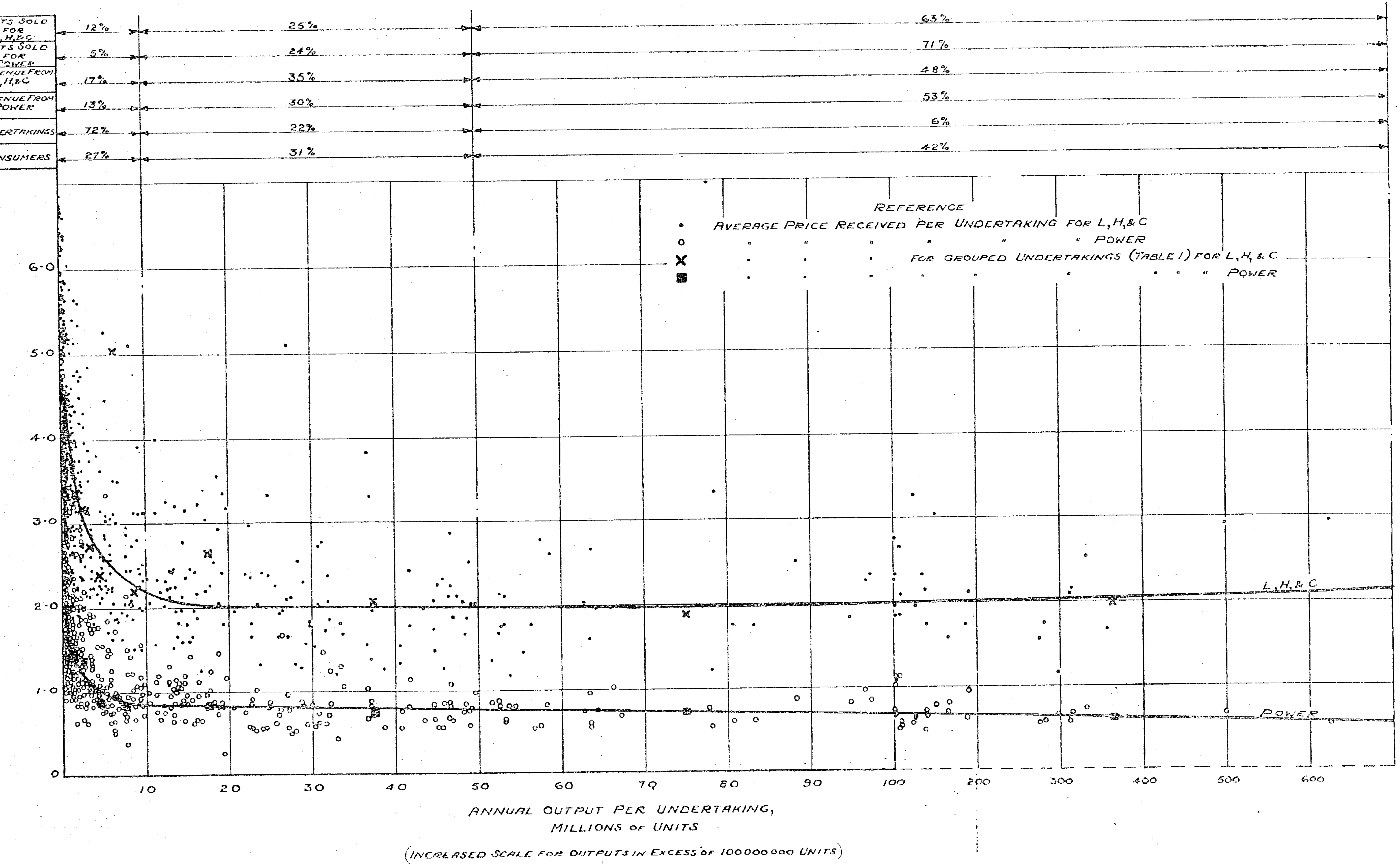

Fig. 2.—Relation between charges and annual output, also the distribution of consumers, etc.

average price per unit charged by each undertaking is shown graphically in Figs 1 and 2, with average annual consumption and output of undertaking as the bases of the respective curves.

Considering Table 2 it will be seen that the average consumption per domestic consumer (col. 9) varies inversely with the average charge per unit made for domestic supplies (col. 7); this charge is also seen to be a function of the annual sales of the undertaking and there is a suggestion that the average consumption and income (cols. 9 and 10) for domestic purposes is proportionately greater for those undertakings with annual sales in excess of 10 million units.

Fig. 2 indicates that the average charges made for both power and domestic sales cover a wider range of charges for a limited consumption in the case of the smaller undertakings with annual sales of less than 10 million units. The tendency should be noted, however, of the average domestic charge per unit to increase for undertakings with annual sales of 100 million units and over.

Table 3

Average consumption per domestic consumer for undertakings	Number of undertakings
kWh per annum	
0 to 100	5
100 to 150	22
150 to 200	36
200 to 250	36
250 to 300	40
300 to 350	62
350 to 400	63
400 to 450	50
450 to 500	48
500 to 600	77
	Total = 439
600 to 700	50
700 to 800	44
800 to 900	19
900 to 1 000	15
1 000 and over	30

The chief point of interest in Table 2 is the relatively small annual consumption for domestic purposes. Even for the largest undertakings the grouped domestic consumers do not achieve an average consumption of 1 000 units per year. The further analysis in Table 3 shows that there are 439 undertakings with average domestic consumptions less than 600 units per year. The distribution of consumers, etc., shown at the top of Fig. 2, indicates 72 per cent of the total undertakings with annual sales of less than 10 million units, and this very high percentage of undertakings embraces only 20 per cent of the total consumers. The facts that 72 per cent of undertakings (Groups 1–13, Table 2) have only 20 per cent of domestic consumers and that the average annual consumption for this large proportion of undertakings is only 378 units, lead to the conclusion that domestic supplies are grossly under-developed in the case of the smaller undertakings.

Reasons for Lack of Development in Domestic Consumption.

In the view of the author the present low and decreasing rate of domestic consumption is one of the most serious modern factors hindering the proper growth of electricity supply. The reasons which are advanced to account for this mal-development are as follows:—

(1) Prices for domestic supply are generally too high to permit of the extensive use of electricity, and reductions in price tend to follow an increased demand, instead of preceding it. As a result the domestic load continues to be restricted, the fixed charges per unit sold remain high, and a condition of expanding demand with consequent falling costs becomes impossible of achievement. This is particularly true for undertakings selling less than 10 million units per annum.

(2) Electricity for power purposes is sold, in many cases, at charges which are unremunerative and which are considerably below the equivalent cost of production by private plant. The effect of this is to place on domestic charges a burden which prohibits the domestic load from increasing to the point at which its inherently high diversity, etc., make it profitable. This applies chiefly in the case of the larger undertakings.

(3) The absence of a unified tariff basis and a unified scale of charges for electricity causes anomalies and inequities which have a psychological effect in deterring consumption.

The reasons which are advanced above are now considered in some detail.

The Relationship between Consumption and Price

If the indications of Fig. 1 are considered with the average annual income data shown in col. 10, Table 2, it will be seen that the averaged annual income from consumers remains approximately constant and is independent of the amount which is charged per unit for domestic supplies, where the average charge per unit is in excess of 2·5d. Where the average charge is reduced below 2·5d. the demand becomes "elastic" and the average annual income increases. This condition of an "elastic" or "expanding" demand is of some importance in view of the fact that electricity is a commodity the sales of which, normally, conform to a condition of "increasing returns," i.e. the cost of providing supply becomes proportionately less as the demand increases, owing to the high proportion of fixed charges which are involved in providing the supply. Hence, if the consumer's demand expands at the lower charges at a greater rate than the reduction which occurs in the cost of providing supply, due to this demand, it is in the mutual interest of the consumer and the supply industry to ensure that the lower charges are made available. This condition is suggested by Fig. 1 to commence when the average price received for domestic supplies falls to approximately 2·5d. per unit sold. In the consideration of this matter from an economic viewpoint, the relationship shown in Fig. 1 may be considered as representing the "value" or marginal significance of electricity to the consumer, i.e. the price which a consumer is willing, or able, to pay for a given amount of electricity for domestic purposes.*

In order clearly to illustrate the matter, an empirical curve of the "value" of electricity has been drawn in Fig. 3. The data used in building the curve have been obtained from various sources (detailed in Fig. 3), each of which consists of a careful investigation into the amount of money that consumers of varying classes are actually paying annually for their electricity. The isolated point (J), which refers to the author's house, is probably a fairly close approximation to the maximum price per unit for domestic supplies which the majority of people would be prepared to pay for the quantity of electricity which is represented by the point on the curve, and it is unlikely that the cost of alternative means of lighting, heating, etc., would be appreciably different in any area of supply. At the lower ranges of consumption, particularly, the curve should not be looked upon as an accurate quantitative representation of the "value" of electricity for domestic purposes but rather as a means of emphasizing the feature that, at low consumptions below, say, 600 units per year and above a corresponding charge of 2½d. per unit, there are no indications of an expanding demand. It will also be seen from col. 10, Table 2, that the range of average income from groups of consumers remains constant despite the decrease in charge, but as the equivalent charge per unit falls below approximately 2½d. a small decrease in the charge will induce proportionately greater consumption and a higher annual income from the consumer.

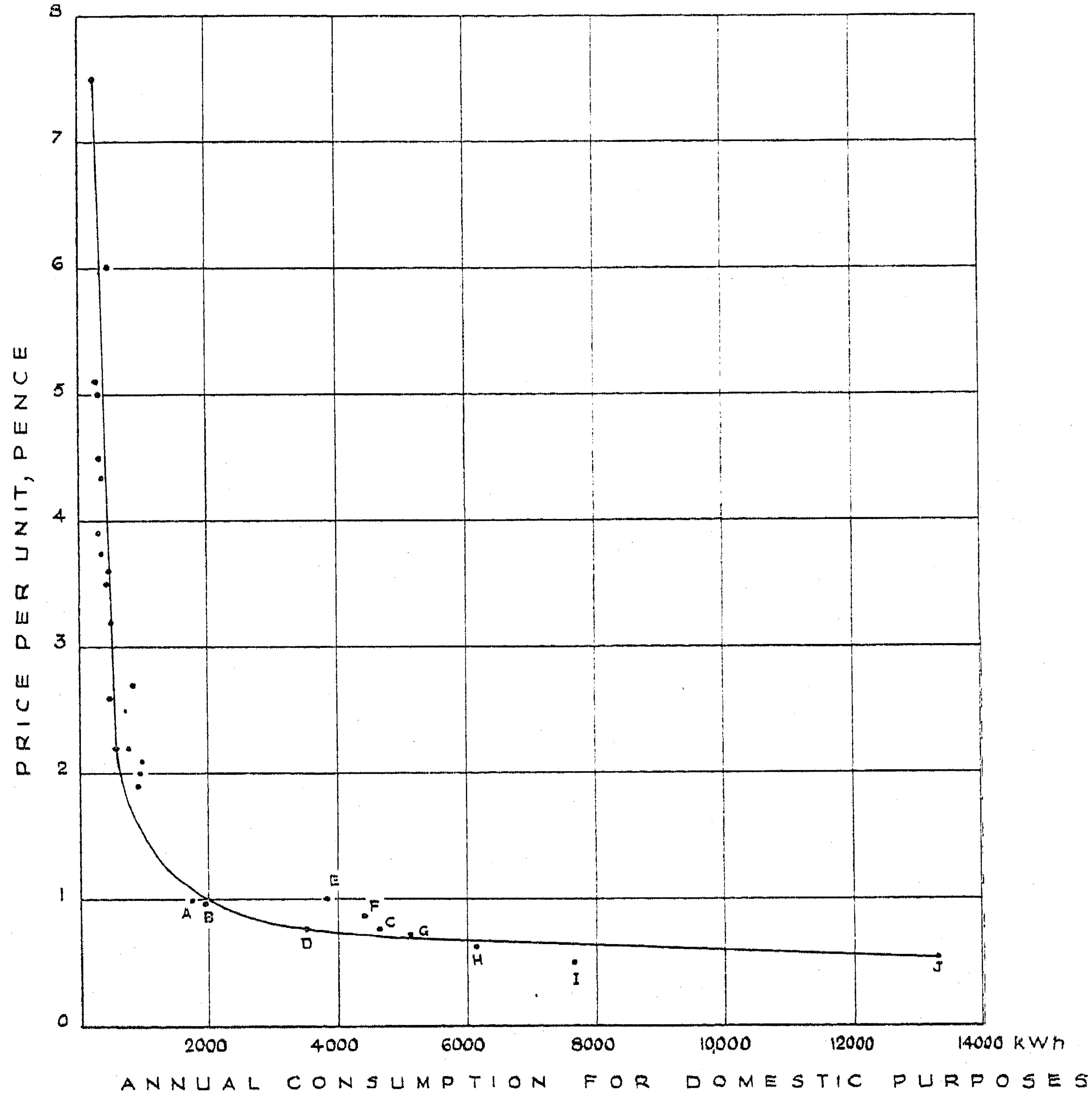

Fig. 3.—Curve illustrating the approximate "value" of electricity.

Origin of points on curve:—

Points below 1 000 units, from Table 2.
Points A and B, from E.D.A. publication No. 1288: "Electric service in the small house," September, 1935.
Points C to I, from *I.E.E. Journal*, 1926, vol. 64, p. 289.
Point J, from figures relating to author's house.

A reduction in charges so as to bring the average price for supply below the critical point which has been indicated is of mutual benefit to the consumer and to the undertaking. It has been mentioned that electricity is a commodity the sales of which are subject to "increasing returns" and that an increased demand can be met at a decreasing cost because the fixed charges of providing supply remain constant, within limits, at any output. An expanding demand will therefore result in reduced costs per unit, due to the larger number of units sold per £ of annual distribution costs, and it will also result in an improvement in the load characteristics of the system, which will be reflected in a reduced cost of generated or purchased supply. The effect of increased sales is shown in Fig. 4, which indicates the component cost for all local authority undertakings for 1934–35) grouped in order of size.

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* The standard economic definition of "price" is used here, i.e. that this "price" is "value expressed in terms of money."

Table 4

ANNUAL LOAD FACTOR FOR VARIOUS GROUPED CLASSES OF CONSUMERS

Item	1	2	3	4	5
	Brief description of conditions	Total connected load	Annual consumption	Average demand per consumer from summation of groups of such consumers	Annual load factor of group*
		kW	kWh	kVA	per cent
1	Small house in Council housing estate with full electrical equipment but one multi-purpose coal fire . .	15·5	900	0·35	29·3
2	Medium size with small appliances	2·1	750	0·37	23·1
3	Medium size, with electric heating and cooking installed but not used exclusively	13·2	2 200	0·80	31·5
4	Small house with full electrical equipment and liberal use	20·7	9 500	3·80	28·5
5	Three-roomed house—lighting only	0·15	80	0·05	18·3
6	Ten-roomed house—lighting only	1·2	420	0·21	22·8
7	Fifteen-roomed house—lighting only	2·2	775	0·39	22·7
8	Small shop (lighting only)	0·1	80	0·08	11·4
9	Larger shop (lighting only)	1·8	770	1·37	6·4
10	Industrial works running 1 shift per day	—	—	—	22·4 to 33·6

Items 1–9 abstracted from *I.E.E. Journal* (1932, vol. 71, p. 852).
Item 10 abstracted from *I.E.E. Journal* (1935, vol. 77, p. 310).
The annual load factor of the single consumer in Item 10 has been multiplied by the diversity factor of 1·6 which was found to apply to the group of power consumers for the whole undertaking.

* Values in this column include the effect of diversity between the consumers in each group.

Comparison of Modern Characteristics of Power and Domestic Supplies.

Fig. 2 indicates a wide difference between the average charges made for power and those for domestic purposes. This distinction between the two types of load would be unnecessary if there had been in the past a healthy rate of increase of domestic supplies, encouraged by the provision of a suitable standard tariff basis and by price reductions which would permit of the elimination of the "small" domestic consumer. A rational and progressive view of the domestic load would not regard normal domestic supplies as having a greater "value" than normal power supplies. At the present time the chief feature of the domestic load is a policy of high prices and low average consumptions, largely because of the opportunist attitude which most undertakers take up when they are commencing to develop a new area. The charges for domestic supply are then set at a high figure so as to obtain the small initial amount of potential domestic load in the area which can be obtained quickly at a high price as it has a high "value." Owing to the lack of financial and technical co-ordination between undertakings, this method of tariff-making and charging is necessary because it permits of the almost inevitable losses which will occur in the initial stages of the undertaking being recouped fairly quickly. An examination of the tariffs and average prices received by most of the undertakings which have commenced operations in new areas within the last few years will show that prices higher than those of the older established undertakings are being charged for domestic supplies, whereas low prices which will not permit of subsequent large reductions have been offered for power supplies. The distinction between the two types of supply and the "small domestic consumers" in this manner is then perpetuated because subsequent reductions in domestic tariffs are usually offered only when the domestic load increases instead of being offered in advance so as to stimulate the domestic load. An individualistic method of charging such as this results in a "vicious circle" which the domestic consumer is powerless to break. The power consumer, on the other hand, has much greater facilities for bargaining with the undertaking to reduce his price, e.g. the threat of installing private plant and by the very nature of his load, which is usually large and the source of important revenue to the supply authority; subsequent reductions in charges will therefore tend to benefit the power consumer at the expense of the domestic consumer, who may actually be of greater benefit to the undertaking when he is using the supply on a large scale, than the normal power consumer.

During recent years there has been considerable investigation into the load characteristics of the domestic consumer, and it has been shown that diversity has an important effect upon the domestic load.* An investigation of this nature was made by Messrs. Woodward and Carne over a number of years, and the characteristics which these authors found to relate to groups of consumers of various classes are given in Table 4. Item 10 was derived from the author's investigations of power load on a system with approximately 14 million units annual sales. (It should be noted that the annual load factors for all the items shown in col. 5 of Table 4 relate to the "group" of consumers and include the effect of diversity between the consumers in that group. The figures in col. 5 of Table 4 may be considered as the "diversified load factor" for a group of consumers.)

Table 5 has been prepared to illustrate the characteristics of a well-developed domestic load for undertakings which have a negligible power load available (items 1–6) and which have therefore concentrated almost exclusively upon the development of the domestic load. If, when considering the lower portion of Table 5, the Lancaster and Wolverhampton undertakings are excepted, owing to certain individual power consumers having exceptionally high load factors, it will be seen that the system load factors do not differ appreciably between the undertakings with a power load equal to 80 per cent of the total and those undertakings which have a power load that is negligible. It will also be noticed that, in the cases where the proportion of power to total load is high, the average price charged for domestic supplies remains higher than for those undertakings with a small proportion of power to domestic load.

It has already been noted that the average consumption per domestic consumer varies inversely with the price charged for the supply, and this feature will again be noted in comparing cols. 6 and 8 of Table 5. One of the considerations to be borne in mind when comparing the two sets of undertakings in this Table is the financial and social status of the consumers which are represented. It may appear, at first sight, that the higher average consumptions of the consumers of under-

Table 5

SHOWING THE HIGH SYSTEM LOAD FACTORS OF UNDERTAKINGS WITH A DEVELOPED DOMESTIC LOAD AND NEGLIGIBLE POWER LOAD (ITEMS 1–6)

Item number	Undertaking	Ratio of domestic and power sales		System annual load factor	Average charges for energy		Average annual domestic consumption per domestic consumer*	Average annual income per domestic consumer*	(Distribution capital expenditure) ÷ (total consumers)
		Domestic	Power		Domestic supplies	Power supplies			
1	2	3	4	5	6	7	8	9	10
				per cent	pence/kWh	pence/kWh	kWh	£	£
1	Hampstead.. ..	1	0·03	30·1	1·58	0·6	1 280	8·4	23
2	Harrogate	1	0·10	29·3	1·25	1·7	1 080	5·6	34
3	Eastbourne.. ..	1	0·11	32·1	1·28	0·88	1 600	8·5	37
4	Beckenham ..	1	0·10	31·4	1·66	1·00	910	6·3	26
5	Southport	1	0·15	31·4	1·60	1·42	1 020	6·8	33
6	Hendon Co. ..	1	0·20	29·2	1·68	1·06	870	6·1	22
	(Averages) ..						1 060	6·9	
7	Wolverhampton ..	1	3·81	46·8	1·85	0·50	620*	4·8	32
8	Bury	1	3·94	35·0	2·26	0·61	520*	4·9	26
9	Paisley	1	4·46	27·7	2·09	0·65	510*	4·3	35
10	Lancaster	1	5·0	45·1	2·12	0·49	740*	6·5	48
11	Birmingham ..	1	5·0	33·7	2·90	0·68	575*	7·0	47
12	St. Helens	1	6·9	38·2	2·10	0·57	430*	3·8	29
	(Averages excluding Birmingham) ..						530*	4·7	

The total consumers have been assumed domestic consumers for items 1–6.

* 90 per cent of the total consumers have been assumed domestic consumers for items 7–12.

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* B. HANDLEY: *Journal I.E.E.*, 1936, vol. 79, p. 507; also E. H. E. WOODWARD and W. A. CARNE: *ibid.*, 1932, vol. 71, p. 852.

takings 1–6 is due to the ability of these consumers to pay larger annual sums for electricity than the consumers in the industrial areas which are represented by undertakings 7–12, i.e. that the "value" of electricity to the first class of consumer is greater than for the second class owing to the ability *and willingness* of the former consumers to pay larger annual sums of money for electricity. The willingness of the first class of consumer is clear when it is realized that they obtain exactly 100 per cent more electricity for an additional annual payment of only 47 per cent. But it is not necessarily true that the second class of consumer is unable to afford to pay the larger amount of money. An investigation carried out by the E.D.A. (Publication No. 1288, September 1935) shows that the small household (comprising a dwelling with a rateable value of £15 per annum or less and consisting of not more than 5 rooms) does actually pay between 2s. 6d. and 3s. 6d. per week for an amount of lighting and heating by means other than electricity and that an equivalent amount of energy could be obtained electrically for a consumption of 1 560 units per year at 1d. per unit, or an annual sum of £6·5.

Table 5 illustrates that the "diversified load factor" (as in col. 5 of Table 4) of the domestic load is approximately equal to that of the more developed power load, apart from special instances of abnormally high-load-factor power demands. The wider development of the domestic load by an undertaking which already has a large power load would result in a more equal sharing of plant and mains that would benefit mutually the two types of load. This is instanced by the case of Wolverhampton (item 7, Table 5) which has recently achieved a relatively large development in domestic load and will be observed to have the lowest average domestic charges of the six industrial undertakings shown in Table 5.

Analysis of Causes of Low Domestic Consumption

In the survey of domestic consumption which has been made up to this point, it has been suggested that consumption for domestic purposes is very low and that this is one of the factors contributing to high prices. Before making an analysis of the causes of low consumption, it is necessary to define the amount of consumption which may be termed low, medium, or high. A definition of "low" consumption is provided in Figs. 1 and 3, where it will be seen that when the average price exceeds 2·5d., which corresponds to an annual consumption of approximately 600 units, a large decrease in price results in only a small increase in consumption. A decrease in price from 2·5d. to 1d. per unit (which corresponds to an annual consumption of 2 000 units) has a greater effect in stimulating consumption, and at any point further along the curve a very small decrease in price results in a very large increase in consumption. For the purpose of this paper, the three stages noted above are considered as the ranges of "low," "medium," and "high" consumption, respectively. It is also assumed that the consumption is determined entirely by the price charged in the medium and high range of consumption, but that the price is not the primary factor at the low range of consumption. An analysis of the causes of under-developed domestic consumption is therefore an analysis of the prices which are charged for electricity.

Fig. 2 shows clearly that the price charged is a function of the size (i.e. annual sales) of the undertaking, and the manner in which average charge, consumption, and annual income, for domestic supplies vary with the size of undertaking will be seen in cols. 7, 9, and 10, of Table 2. The reason for this relationship will be seen in Table 6, which is the result of an analysis based upon the *Electrical Times* "Tables of Costs and Records" for 1935 and which relates to most of the local authority undertakings; the results are shown graphically in Fig. 4.

The chief purpose of Table 6, in indicating the causes of low consumption, will be seen in the interaction of costs and consumption shown in cols. 8, 9, and 10. The cost per unit in cols. 5 and 6 are the costs of distribution, except for the component of running cost of current, which is included in col. 6. It is maintained in the paper that all the component costs of providing supply are fixed costs except for the items of losses and the running cost of current, i.e. that they are related either directly to capital expenditure or to the number of consumers. In considering Table 6, therefore, the total cost of providing supply (per unit sold) shown in col. 8 may be looked upon as being due to fixed charges, after an amount approximately equal to 0·25d. per unit has been deducted to cover the running cost of current and losses.

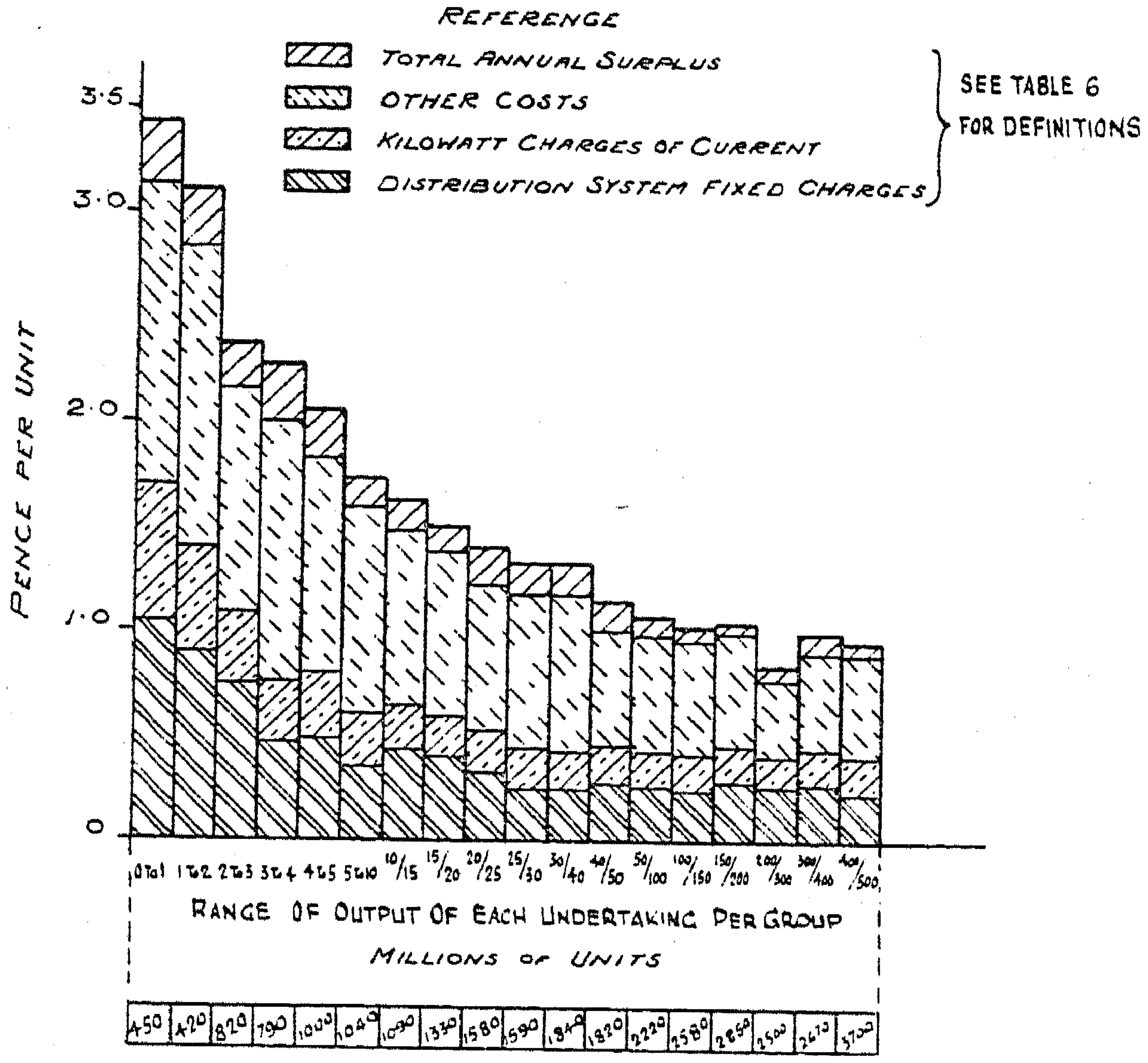

Fig. 4.—Component costs of providing supply for grouped undertakings (local authorities).

Comparing cols. 10, 9, and 8, of Table 6, it will be seen that the small number of units sold per £ for the first three groups of undertakings and the low average consumption results in a high cost per unit sold, due to the undeveloped use of the plant, mains, and administration, which are represented by the fixed costs of generation and distribution. The larger undertakings have been able to make a greater use of mains and administration by developing the power load, with the reduction in total cost per unit sold that is shown in cols. 8 and 5. The difficulty of the smaller undertakings in obtaining an increase in consumption is clear. Fig. 3 shows that the reduction in price that is required to obtain a marked increase in consumption can only be obtained by offering an average price between 1d. and 2½d. per unit (and preferably below 1d.). The offer of this price would result in increased consumption, but with a time-lag dependent upon many factors. For the first six groups of undertakings, particularly, the offer of these low prices would result, temporarily, in selling electricity at less than the average cost of production, and a deficit would be likely to occur. The engineers in charge of these smaller local-authority undertakings would probably have some difficulty in convincing their committees that the policy suggested in this paper was economically sound. The larger undertakings could afford to offer electricity for domestic supplies at an average rate of, say, 1d. per unit, but the indications of col. 7, Table 2, do not suggest that this course is being generally pursued. Here again, the possibility of even a temporary financial deficit will deter most local-authority committees, and some company undertakings, from adopting a policy of offering reductions in charge in advance of the increase in demand. The position was stated by Mr. Kennedy and Miss Noakes in their paper (already referred to) in these words: "There appears to be a vicious circle, starting with high tariffs, followed by low consumption, followed by high cost per unit, and so back to high tariffs." The first reason which was advanced earlier in the paper to account for the mal-development of domestic supply will now be seen.

Table 6

COMPONENT COSTS OF PROVIDING SUPPLY, FOR GROUPED LOCAL-AUTHORITY UNDERTAKINGS

Item number	Size of undertaking in group (annual sales in units)	Number of undertakings in group	Various charges expressed per unit sold for all purposes					Units sold per	
			Generation fixed annual charges	Distribution system fixed annual charges	Other costs	Surplus	Total	Consumer	£ of distribution capital
1	2	3	4	5	6	7	8	9	10
	millions		pence per unit sold	pence per unit sold	pence per unit sold	pence per unit sold	pence per unit sold	kWh	kWh
1	0 to 1	22	0·65	1·05	1·43	0·31	3·44	450	17
2	1 to 2	19	0·50	0·90	1·43	0·29	2·37	420	16
3	2 to 3	20	0·34	0·74	1·08	0·22	2·38	820	18
4	3 to 4	17	0·28	0·47	1·24	0·16	1·75	790	24
5	4 to 5	16	0·32	0·48	1·02	0·22	2·04	1 000	17
6	5 to 10	34	0·26	0·34	1·00	0·13	1·73	1 040	40
7	10 to 15	28	0·21	0·43	0·82	0·15	1·61	1 080	78
8	15 to 20	16	0·20	0·40	0·77	0·13	1·50	1 350	50
9	20 to 25	11	0·21	0·31	0·70	0·19	1·41	1 580	40
10	25 to 30	14	0·20	0·24	0·73	0·15	1·32	1 590	44
11	30 to 40	21	0·19	0·26	0·61	0·15	1·21	1 820	85
12	40 to 50	11	0·17	0·27	0·55	0·16	1·15	2 220	65
13	50 to 100	28	0·18	0·25	0·56	0·09	1·08	2 580	80
14	100 to 200	12	0·18	0·27	0·53	0·06	1·04	2 850	51
15	200 to 300	3	0·14	0·26	0·38	0·04	0·82	2 500	53
16	300 to 400	2	0·17	0·27	0·47	0·08	0·99	2 670	45
17	400 to 500	2	0·18	0·22	0·32	0·03	0·75	3 700	65

Definition of Charges, etc.

Col. 6. " Other costs " comprise:—Salaries and wages, repairs and maintenance and stores; distribution; rent, rates, and taxes; management, salaries, insurance, etc.; running cost of energy purchased or generated.

Col. 4. " Generation fixed charges ":—Kilowatt charges for energy, estimated for each undertaking at £3·25 per kVA and known load factor.

The cost of production (per unit sold) is higher for the smaller undertakings than the price which must be offered to obtain an " expanding demand " in the domestic supply. The individualistic financial policy which exists in the supply industry prevents the smaller undertakings from undertaking the risk of incurring a temporary financial deficit such as may occur if reductions in price were offered in advance of the increase in demand. The larger undertakings are in a position to adopt this course without the risk of incurring such heavy financial deficits, but in many cases it would seem that reductions in price are only offered after the demand has increased.

FACTORS INFLUENCING POWER SUPPLIES

General.

Probably the main feature which emerges from a study of the power and domestic loads is that there is a very large potential domestic load which can only be obtained by a large reduction in charges. The education of the domestic consumer to realize that electricity is better and cheaper to use than other forms of energy is a secondary matter which must essentially follow reductions in charge by the majority of undertakings. As regards the power load, however, whilst there is a potential load available which approaches in amount to the potential domestic load, a reduction in average charge is unnecessary and, in the author's view, not possible of achievement if sound economic principles are to be observed. The view that power charges are too low is given after a long experience and investigation into the cost of running private plant and a wide experience of the charges that prevail to-day for power supplies. The cost of running private plant is capable of much closer generalization than is often appreciated, and an important service would be rendered to the supply industry if an authoritative body were to collate information on this point and if the results of the comparative inquiry were published and studied by all supply engineers and power consumers. The matter is of national importance because power consumers tend to be obsessed by the alleged need for still cheaper electric power, and industries follow cheap electric power, often without regard to other features which may ultimately have an equal influence upon their cost of manufacture. This matter, when considered in conjunction with the policy which obtains with manufacturers of bargaining with an undertaking for lower prices by demanding the lower tariff of some other undertaking, which is often irrelevant to the real circumstances, is sufficient to demand close consideration of the national unification of power charges, even though such a course involved financial co-ordination between undertakings.

The most recent census of production returns show that 8·1 million kW of private plant are still in use in this country. If an average annual load factor of 28 per cent is taken for the use of this plant there is represented a potential load of 20 000 million units per year available to public supply. An investigation in 1935* as to the costs of running 4 658 kW of private plant showed that the average cost per unit was 1·41d. The chief obstacle to the change-over of private plant of this nature has been the hesitation or inability of many manufacturers to finance the change-over. This obstacle should temporarily disappear during the present trade boom, but it will re-appear when trade again becomes normal. In view of the fact that the new plant required is now standard for practically all supply areas, it would be in the interests of the electrical manufacturing and supply industries if a public body could be set up to finance on easy terms the change-over from private plant to public supply.

The author fully appreciates that industry is entitled to obtain electricity for power purposes at the lowest possible cost, if it is to compete successfully in foreign markets. It should be realized, however, that in the year 1921–22, 2 105 million units were used from the public supply for power purposes at a cost to industry of £15 million, whereas in 1934–35, 7 285 million units were used, or an increase of at least 250 per cent in productive capacity, at an increased cost of only £6 million, or 40 per cent. If the assumption made later in the paper is a correct one, viz. that the unduly low charges to power consumers are hindering the development of domestic supplies, the effect of these low charges will ultimately be to delay the further reductions in charges for power, which a well-organized and efficient supply industry could, indeed, provide. A temporary cessation of the general reduction in charges for power supplies would permit of reductions in domestic charges below the critical point required to cause a very large expansion of the domestic demand. This increase in domestic demand would, in its turn, produce improvements in the characteristics of the total supply that would be reflected in lower costs of production. The lower costs would ultimately permit the annual reduction in power charges to commence again, but on a sounder economic basis.

The Economic Cost of Power Supplies

It has been stated earlier that one of the reasons for low domestic consumption is that domestic charges are too high; it is now suggested that the prices for power are too low. The differentiation which is made between the two classes of supply has been suggested as an irrational one, based upon tradition which overlooks the valuable characteristics that are inherent in a developed domestic load. The differentiation is apparent in the methods adopted in estimating the cost of providing power and domestic supplies, respectively. The author would question the soundness of the theory that large amounts of energy required for power purposes can be supplied at or below the cost of generation, because the costs of distribution are eliminated and the load factor of the power load is greater than the load factor of the domestic load. With the extensive modern supply systems now in use, the capital expenditure on transmission and secondary mains is an important item of the total capital and must rank as a necessary cost of which a large proportion must be allocated to power supplies. Also, data have been presented in Table 5 to show that the system characteristics of even a partially developed domestic supply are equal to those of a normal and developed power supply. It will be seen from Table 1 that the domestic load for the whole country has risen from 38 per cent of the power load in 1927–28 to 63 per cent in 1934–35, and the data in Table 5 would suggest that there may be an approximately equal sharing of generating plant by the two classes of load, when the supplies are considered from a national point of view.

An approximate view of the contribution made by the power supplies towards distribution costs and charges is given in Table 7. The total costs of generation, per unit sold, have been abstracted and extended from the paper by Mr. Kennedy and Miss Noakes, and are given in col. 1 for the years 1921–35. The revenue per unit obtained from power supplies for the whole country is shown in col. 2. The difference between the cost of generation and the revenue (per unit sold) received from power supplies is then represented in col. 3, and the total monetary surplus which is then available from the power supplies towards the costs of distribution is shown in col. 4. Col. 5 then shows the percentage contribution (as represented by the surplus in col. 4) made by power supplies in each year towards the total cost of distribution, after deducting the cost of generation. It would seem that an entirely disproportionate amount of the cost of distribution is being borne by the domestic supplies. This observation supports the second reason which has been advanced to account for the poor development of domestic supplies, viz. that the domestic load has been hindered from developing owing to the heavy and disproportionate burden of charges which it has had to bear.

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* *Journal I.E.E.*, 1935, vol. 77, p. 314, Table 2.

Table 7

AMOUNTS SUBSCRIBED BY POWER AND DOMESTIC SUPPLIES, RESPECTIVELY, TOWARDS TOTAL COSTS OF DISTRIBUTION

Year	Cost of generation per unit sold for all purposes	Revenue received per unit sold for power purposes	Surplus available towards total cost of distribution		Surplus (Col. 4) expressed as contribution towards the total cost (£) of distribution	Contribution towards total cost of distribution made by domestic supplies
			Per unit sold (i.e. Col. 2 less Col. 1)	Total amount (i.e. Col. 3 × units sold for power)		
	1	2	3	4	5	6
	pence/kWh	pence/kWh	pence/kWh	£ millions	per cent	per cent
1921–22	1·690	1·690	nil	nil	nil	88·0
1922–23	1·258	1·300	0·042	0·377	2·9	86·0
1923–24	1·116	1·140	0·024	0·307	2·2	87·9
1924–25	1·037	1·070	0·033	0·482	3·2	86·4
1925–26	0·938	1·000	0·062	0·972	5·9	85·1
1926–27	1·057	1·140	0·083	1·301	7·6	82·4
1927–28	0·832	0·940	0·118	2·231	10·6	79·3
1928–29	0·748	0·860	0·113	2·32	10·2	79·7
1929–30	0·698	0·820	0·122	2·56	10·0	80·0
1930–31	0·676	0·810	0·134	3·00	11·3	78·7
1931–32	0·640	0·790	0·150	3·39	11·8	78·2
1932–33	0·616	0·770	0·154	3·66	12·0	77·9
1933–34	0·570	0·733	0·163	4·34	13·1	76·8
1934–35	0·531	0·689	0·158	4·79	13·3	77·7
1935–36	0·510	0·659	0·149	5·12		

Domestic charges are usually calculated with care and scientific precision in the hope of ensuring that every domestic consumer shall pay his correct proportion of the cost involved in providing his supply, but a much larger element of speculative and commercial risk is permitted in ascertaining the cost at which power supplies are provided. This anomalous (and myopic) method of costing results in domestic charges remaining high because they do not envisage a high rate of domestic development. The earlier discussion on the relationship between consumption and price showed that the correct policy which should be adopted in order to obtain an expanding domestic load is to offer a tariff for which the charge per unit would not exceed 2½d. for even the smallest consumer, the charge being graduated so as to comply with the curve shown in Fig. 3. An intensive development campaign should then be carried out so as to promote the consumption of the small consumers, and the results upon costs and consumption observed over, say, 3 years. It is unlikely that any of the individual undertakings would be permitted to embark upon a policy of this nature. It is suggested that the Electricity Commissioners should obtain power to develop a "demonstration area" on the lines suggested above; the results would be of great benefit to the supply industry.

The conclusion reached by the author, after examining in this manner the contribution made by power supplies towards the costs of distribution, is that the domestic supplies are being required to make a contribution to the distribution costs and charges which is greatly in excess of the fixed charges actually incurred in respect of domestic supplies. It would follow that power supplies are being sold at less than the real cost of production, when considered from a national point of view with the supply industry as one single supply undertaking. It is for this reason that the need is advocated, in this and in a previous paper by the author, for a competent body to study closely the lowest cost at which power can be supplied in competition with private plants and then to ascertain whether the supply industry can afford, or is required to continue, to supply at the present prices. It is suggested that the need for public supply to meet competition with private plants does not justify the low prices at which power is obtained, apart from a relatively few special cases where such a need may prevail.

The unnecessarily low prices obtained for power are due to the lack of knowledge in the supply industry as to the prices which are competitive with private plants. A further reason is the need for "cutting" public supply prices, which exists owing to the strong and often intimidating pressure on the part of industrial power consumers to obtain a price for power which is lower than that of some other undertaking. The position may be described as one in which the prices quoted for power are not determined primarily in relation to the feature of actual cost or even of comparative cost with competing private plant; rather are they quoted on a system commonly described as "Dutch auctioning." Conditions similar to this, which existed in the electrical manufacturing industries, were appreciated many years ago, and met, by the manufacturers of transformers, turbo-generators, and electrical equipment of a similar nature. It is suggested later in the paper that the much more intense competition which may arise shortly in the electrical supply industry, and the intensified need which will inevitably arise for more efficient working, will cause a condition in which it will no longer be possible to subsidize power supplies at the expense of the domestic supplies. If there is available at that time a more exact knowledge of the competitive costs of power supply, and if this knowledge permits of an enhanced firmness in refusing to provide power supplies at less than the competitive cost (so long as such a course involves supplying at a loss to the supply industry) a wise and necessary step will have been taken to strengthen the whole of the public supply industry.

FACTORS INFLUENCING COSTS AND CONSUMPTION

The total cost (including profit and surplus) of providing a supply of electricity for the country as a whole is equal to the product of the total units sold and the average revenue received per unit sold. If the total cost for any year is expressed as a percentage on the total capital, the relationship between these factors may be expressed as follows, for any given year:—

(Annual return required on capital) $\propto$
(Units sold per £ of capital) $\times$
(Average revenue received per unit sold)

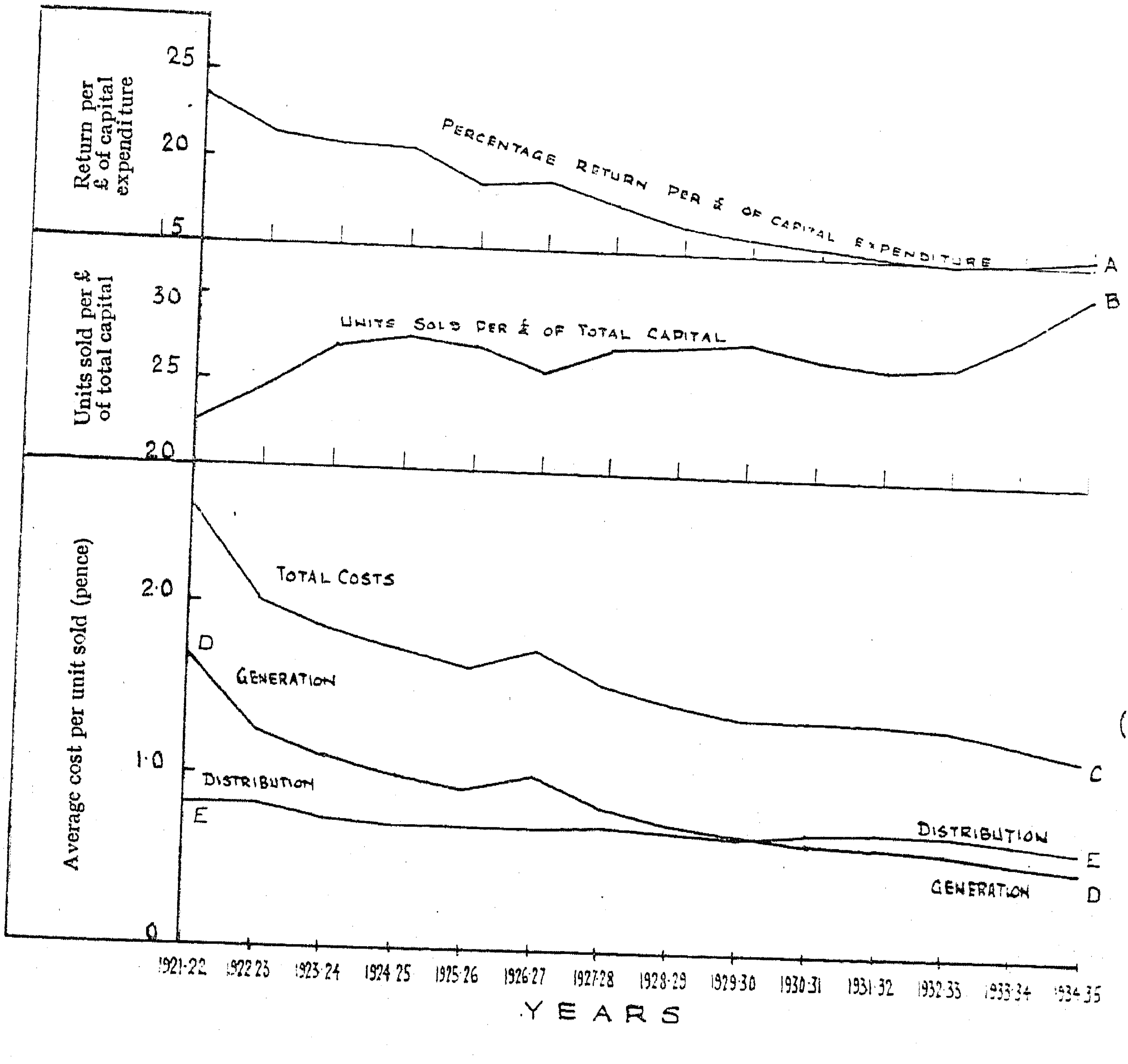


Fig. 5.—Curve showing variations in
(*a*) Percentage return on capital.
(*b*) Units sold per £ of capital.
(*c*) Cost per unit sold.

Factors similar to those above were adopted by Mr. Kennedy and Miss Noakes as criteria for the examination of distribution efficiency for the country as a whole, and the statement made above is a summary of the thesis developed in their I.E.E. paper. They are used here in order to summarize the previous discussion and to examine briefly the present and the possible future trend of supply, particularly as to how the trend may be effected by the connection of large numbers of "small" domestic consumers and by large sales of power which in total may be unremunerative; the correlation of the three factors referred to above is shown in Fig. 5 (curves A, B, and C), and curves B and C will be seen to express the relationship (already discussed) between consumption and charge per unit. A brief examination is now made of each factor.

(a) The Annual Return Required on Capital.

The return required on capital will be seen from cols. 8 and 9 of Table 8 to have fallen steadily from 1921–33 and then to have risen in each of the two following years. (As the increases during 1933–35 have been caused by a fairly rapid increase in the units sold per £ of capital it is likely that the annual return will tend to fall in the next one or two years and to be stabilized at about 15 per cent, assuming a similar rate of increase and decrease, respectively, in the other two factors during that period.) The reason for the large

Table 8

UNITS SOLD PER £ OF CAPITAL AND PERCENTAGE RETURN ON CAPITAL FROM 1921–36

Year	Units sold (all purposes)	Total capital invested	Units sold per £ of generation capital	Units sold per £ of distribution capital	Units sold per £ of total capital	Total revenue received per unit sold	Annual revenue per £ of total capital expenditure	Percentage return per £ of total capital expenditure
1	2	3	4	5	6	7	8	9
	millions	£ millions	kWh	kWh	kWh	d.	d.	per cent
1921–22	3 122	137·8	44·7	46·0	22·6	2·562	56·7	23·6
1922–23	3 762	151·9	48·8	50·3	24·7	2·086	51·7	21·5
1923–24	4 468	165·1	53·2	55·0	27·1	1·854	50·1	20·9
1924–25	5 097	182·2	55·7	54·9	27·7	1·745	48·3	20·7
1925–26	5 606	206·0	56·6	52·4	27·2	1·647	44·9	18·7
1926–27	5 868	227·3	56·5	47·6	25·8	1·759	45·4	18·9
1927–28	7 003	256·5	60·4	49·9	27·3	1·555	42·4	17·7
1928–29	7 800	283·6	61·4	49·8	27·5	1·447	39·8	16·6
1929–30	8 666	310·9	64·1	49·3	27·9	1·385	38·5	16·0
1930–31	9 074	335·5	64·0	46·8	27·0	1·382	37·4	15·5
1931–32	9 501	366	64·7	44·9	26·5	1·360	36·1	15·1
1932–33	10 210	381	67·7	44·6	26·9	1·330	35·8	14·9
1933–34	11 467	400	74·8	46·5	28·7	1·262	38·2	15·1
1934–35	13 030	420	84·5	49·1	31·1	1·195	37·2	15·5
1935–36	15 049	447	92·5	52·9	33·6	1·125	37·9	15·8

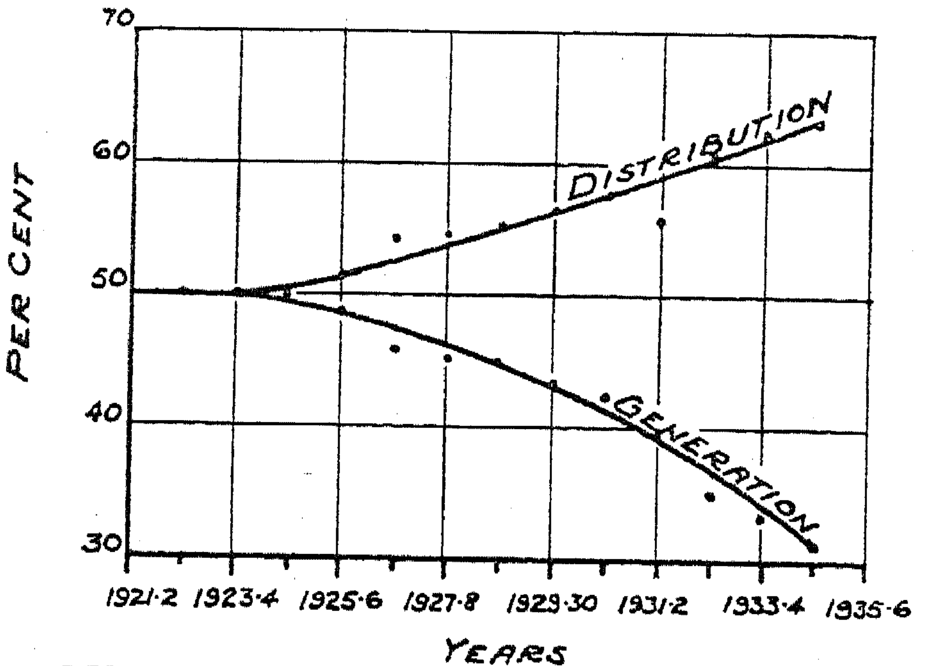
Table 9*

COMPONENT COSTS OF DISTRIBUTION (1921–35)

Year	Repairs and maintenance	Management	Rents, rates, and taxes	Capital charges and surplus	Total distribution	Units sold per £ of total capital	Units sold per £ of annual distribution costs
1	2	3	4	5	6	7	8
	d.	d.	d.	d.	d.	kWh/£	kWh/£
1921–22	0·180	0·154	0·080	0·398	0·812	22·6	291
1922–23	0·152	0·136	0·069	0·471	0·828	24·7	291
1923–24	0·133	0·125	0·060	0·420	0·738	27·1	326
1924–25	0·134	0·118	0·065	0·391	0·708	27·7	339
1925–26	0·133	0·113	0·070	0·393	0·709	27·2	339
1926–27	0·140	0·119	0·086	0·357	0·702	25·8	334
1927–28	0·128	0·109	0·074	0·412	0·723	27·3	344
1928–29	0·128	0·108	0·077	0·387	0·700	27·5	352
1929–30	0·126	0·107	0·086	0·366	0·685	27·9	340
1930–31	0·128	0·112	0·090	0·376	0·706	27·0	332
1931–32	0·131	0·118	0·093	0·382	0·724	26·5	337
1932–33	0·104	0·115	0·087	0·409	0·715	26·9	337
1933–34	0·097	0·114	0·092	0·399	0·692	28·7	348
1934–35	0·091	0·113	0·088	0·372	0·604	31·1	362
1935–36	0·086	0·103	0·081	0·340	0·615	33·6	390

* Table abstracted and extended from *Journal I.E.E.*, 1933, vol. 73, p. 101, Table 6.

decrease in the return required on capital from 1921–31 will be seen from Fig. 5 (curve D) to be due to the decrease in the total costs of providing supply caused by the improvement in generation efficiency. It will be seen that the improvement in generation efficiency has now almost ceased and it may be presumed that a limiting efficiency has almost been reached on the present methods of generation. Any decrease in the total cost of production, and hence in the return required on capital, will require to be obtained chiefly by a reduction in the costs of distribution. Table 9 shows the component costs of distribution as abstracted from the paper by Mr. Kennedy and Miss Noakes, extended to the year 1935–36. It will be noticed how closely related are the total costs of distribution and the units sold per £ of total capital. The value of this latter factor appears to be very sensitive as it will be noted that the slight increase in the total cost of distribution (col. 6, Table 9) in 1925–26 is associated with a reduction in the units sold per £ for 1925–26 and 1926–27; a similar increase in 1930–32 resulted in a corresponding decrease in the units sold per £ for the same years, and the increase in cost for 1927–28 had the effect of causing the units sold per £ to remain almost stationary from 1927–30.



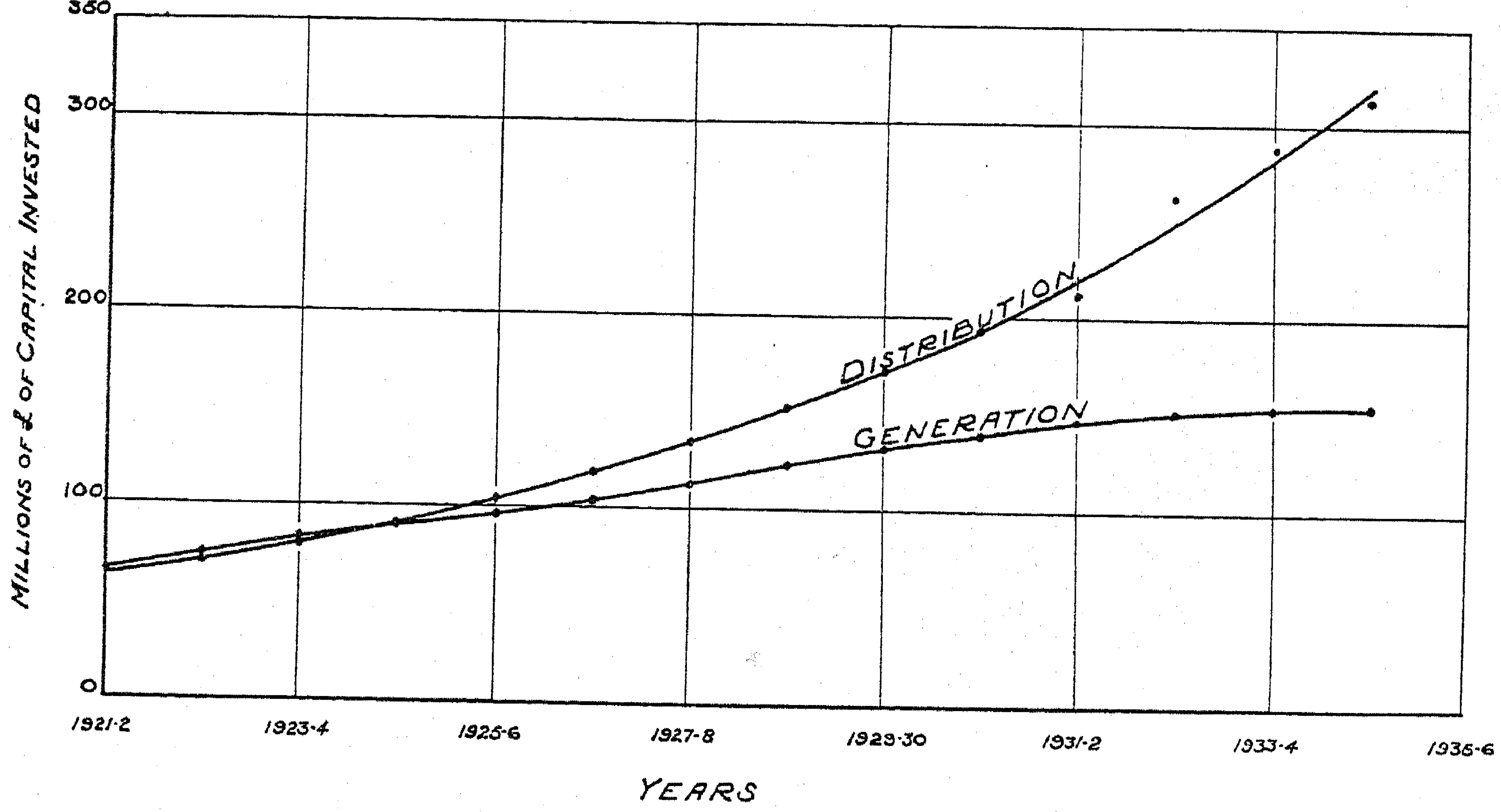


Fig. 6.—Amount of capital invested in generation and distribution.

A study of the nature of the items of cost shown in Table 9 leads to the conclusion that a large proportion of the cost of distribution consists of charges which remain constant and largely independent of the number of units sold. The items of management, repairs and maintenance, and of rent, rates and taxes, are more directly related to the number of consumers, whilst the item of capital charges is related chiefly to the number of actual and potential consumers and particularly to the load characteristics of groups of consumers. It is well known that as more consumers are connected system diversity will increase, and as the consumption of each consumer increases there is a still greater increase in system diversity. So far as the domestic consumer is concerned, a reduction in the cost per unit sold for distribution can only be obtained, primarily, by connecting the largest possible number of consumers and then by arranging for those consumers to increase their consumption. As more consumers are connected, there is a greater use of the capital expended on mains, and hence a reduction in the average capital cost per consumer (see Fig. 9). If this is followed by an increase in consumption, the increased diversity which results will reduce the system fixed charges per unit sold for both generation and distribution. This matter has been referred to at some length because of the strong view which is held by the author, that any successful national unification of tariffs must ultimately revert to a 2-part tariff with a fixed annual "consumer charge" common to and equal for all consumers, independently of the nature or amount of their demand. The advantages and practicability of a tariff of this nature are discussed later in the paper.

The method of dealing with the problem of the increasing number of small domestic consumers is now shown clearly in the preceding paragraph. In the gas industry the problem is being met by increasing the minimum fixed charge to the small consumer; this is not the best method for the electricity supply industry, which must, however, clarify and determine its views on the problem fairly soon. The first need is to view the "small" consumer optimistically, as a consumer with a potential annual revenue equal to at least £5, and then for undertakings to take a reasonable commercial risk by adopting a domestic 2-part tariff with the fixed charge adjusted for the small consumer to, say, £1·5, and the running charge not exceeding ½d. per unit (see Appendix I, item 4, as to the cost of connecting small consumers). It should be considered that each "small" consumer who can be connected to existing mains is ultimately a certain source of profit, and that every consumer so connected reduces the average fixed cost per consumer in the whole country (see Fig. 9 and Table 13). If the policy suggested above were adopted by all undertakings, the way would have been cleared for a successful national publicity campaign to be carried out for the purpose of increasing sales; until a unified tariff and unified charges of this nature are available, any sales campaign must be sporadic and nullified by the suspicion and bewilderment which most consumers entertain regarding domestic electricity supply.

Table 10

Proportion of total cost per unit sold, due to:—

(A) Distribution capital charges and surplus. (B) Total costs of distribution.
(C) Generation capital charges. (D) Distribution total costs plus generation capital charges.

	Year	1922–23	1924–25	1926–27	1928–29	1930–31	1932–33	1934–35
	(A) Distribution capital charges and surplus.							
		per cent	per cent	per cent	per cent	per cent	per cent	per cent
1	Per cent of total cost ..	22·6	22·4	20·3	26·7	27·2	30·7	31·2
	(B) Distribution total costs.							
2	Per cent of total cost ..	39·7	40·7	40·0	48·4	51·2	53·8	55·6
	(C) Capital charges of generation (i.e. exclusive of generation working costs).							
3	Per cent of total cost ..	23·2	22·1	17·2	21·7	19·9	20·3	18·1
	(D) Total of (B) and (C) above.							
4	Per cent of total cost ..	62·9	62·8	57·2	70·1	71·1	74·1	73·7

(b) Units Sold per £ of Capital and Average Revenue received per Unit.

The relationship between the above two factors is the relationship between consumption and price which has been discussed earlier in the paper. The effect of capital expenditure is, however, of some importance in determining the future trend of costs and charges. The growing proportion of capital expended in distribution from 1921 to 1931, as compared with that of generation, was pointed out by Mr. Kennedy and Miss Noakes in 1933. Since 1930–31 the difference has been greatly accentuated, as will be seen from Fig. 6. The influence of this factor upon the future trend of costs will be seen from Table 10. It has already been emphasized that for domestic supply the capital charges of distribution are essentially a "consumer charge," since the cost per unit sold in respect of this item can be reduced only by increasing the number of consumers and thus increasing the potential diversity of the system. The figures shown in Table 10 emphasize the added need to maintain an increase in the average consumption of each domestic consumer and thereby to ensure that the unit cost of distribution shall not increase in the future.

The increase in distribution capital is beneficial so far as it relates to extensions of mains which will increase the potential number of consumers. In this connection it is pointed out that capital which has been expended in recent years upon extensions into rural areas is probably as remunerative as capital expended during the same period in urban areas (see Tables 11 and 12). The only serious points of difference between recently-established rural areas and the older-established urban areas is that the average price charged per unit is much higher for the rural areas and the average consumption correspondingly lower. The statistics of development given in Table 12 for the Chester Rural Area indicate that rural development which is carried out from a previously established load nucleus can, usually, permit of financial equilibrium from the very early stages of development (see Item 3 of Table 12). In the few cases in which a main scheme of transmission and secondary distribution has been installed initially in a rural area and in advance of load development, as in items 6 and 9 of Table 12, it is usual for the scheme to reach financial equilibrium by about the fourth to sixth year. Such cases are relatively few and are unlikely to cause an appreciable reduction in the yield from capital for the whole country. It will also be noted from Table 12 (cols. 1, 4, and 7) that there is evidence of the rural undertakings being able to work on a lower annual return on capital than the urban undertakings (col. 4, Table 11).

Table 11

TABLE SHOWING COMPARATIVE FEATURES OF ESTABLISHED URBAN UNDERTAKINGS AND RECENTLY ESTABLISHED RURAL AREAS

Undertaking 1	(Distribution capital expenditure) ÷ (Total consumers) 2	(Domestic revenue) ÷ (Total consumers) 3	Total revenue as percentage on distribution capital 4	Population per square mile of area 5	Year of operation to which data are related 6
	£	£	per cent		
Established urban undertakings					
Hampstead	23	8·4	31	25 000	41st
Harrogate	34	7·6	25	320	38th
Southport	33	6·7	24	3 450	41st
Birmingham	47	6·3	31	5 000	44th
Liverpool	51	8·4	25	18 000	52nd
Leeds	33	4·2	20	8 100	42nd
Rural undertakings recently developed					
West Midlands J.E.A.	38	5·0	24	210	6th
Chester rural area	31	5·9	19	114	10th
Mid-Cheshire rural area	38	6·6	26	294	10th
Mid-Lincs Co.	27	5·28	31	109	5th
Dumfries C.C.	49	6·23	16	54	4th
Wigtownshire	31	5·4	29	61	4th
Average results of 22 supply areas—mainly rural* and comprising:—	53	9·7†	18	—	—
9 local authorities	38	6·38†	17	—	—
13 distribution and power companies	56	10·46†	19	—	—

* See paper by S. E. BRITTON: "Rural Electrification in Great Britain," Paper No. 173, Third World Power Conference.
† Comprises revenue from all sources.

The tendency of the value of the "units sold per £ of capital" to increase or decrease in the future will be influenced largely by the proportion of capital expenditure upon which the yield is less than the average required to meet capital charges. An instance occurs in the case of a large undertaking which has a developed power load and initially a large proportion of consumers with "medium" annual consumption, but which connects up an increasing proportion of domestic consumers with a constantly "low" annual consumption. These latter consumers produce a yield upon the capital required to supply them which is much lower than the average for the whole undertaking, with the result that they are subsidized by the larger domestic consumers. The effect in this instance, as also in some cases of unremunerative power supplies, is to keep high the average price charged for domestic consumption and thereby to retard the progress of the undertaking. The unremunerative expenditure which may be necessary may therefore be divided into two portions, i.e. that expenditure which will be permanently unremunerative, e.g. expenditure to satisfy the requirements of the Home Office which are necessary for the protection of workmen; the second portion comprises expenditure which may be only temporarily unremunerative, e.g. that necessary to give a supply to a domestic consumer with a low annual consumption. These considerations must, of course, be balanced against the possibly reduced capital costs per consumer as more consumers who are

Table 12

SUMMARY OF DEVELOPMENT AND FINANCIAL RESULTS

Item No.		Year ending 31st March											
		1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937
	Chester Rural Undertaking.												
1	Income shown as a percentage on capital outlay, per cent	14·82	19·64	16·64	16·72*	16·33*	16·77*	15·63*	16·10	17·50	18·97	19·08	
2	Annual load factor, per cent ..	—	—	27·3	24·0	35·3*	43·4*	43·5*	50·6	51·2	48·0	38·0	
3	Surplus (S) or deficit (D), £ ..	(D) 267	(S) 522	(S) 1 474	(S) 3 533*	(S) 2 246*	(S) 1 021	(D) 1 446	(D) 1 172	(S) 597	(S) 1 485	(S) 1 004	
	West Midlands J.E.A. (Rural Area)												
4	Income shown as a percentage on capital outlay, per cent	—	—	—	—	—	1	7	10	15	17	20	24*
5	Annual load factor, per cent ..	—	—	—	—	—	—	—	22	26	33	39	35*
6	Surplus (S) or deficit (D), £ ..	—	—	—	—	—	(D) 1 000	(D) 6 500	(D) 8 000	(D) 3 500	(D) 650	(S) 5 000	(S) 9 500
	Mid-Cheshire (Rural Area)												
7	Income shown as a percentage on capital outlay, per cent	8·66	13·3	15·03	17·55	20·3	20·25	22·8	23·1	23·6	24·8	—	—
8	Annual load factor, per cent ..	—	21·6	25·9	24·0	25·6	23·5	32·1	30·5	36·8	33·5	—	—
9	Surplus or deficit, £	(D) 2754	(D) 1 337	(D) 767	(S) 114	(S) 1 252	(S) 1 445	(S) 2 004	(S) 3 230	(S) 2 640	(S) 4 513	—	—

* Denotes reduction in charges during that year.

yet unconnected but are on the route of existing mains become connected at the cost of the service only (see Fig. 9).

In considering the first class of expenditure it is necessary to take into account many influences which have not hitherto been effective in any large degree. The requirements necessary to provide additional safety to workmen and to consumers are rapidly becoming more stringent, and to these must be added the more stringent supply regulations which are being enacted and which will become increasingly necessary in order to provide an improved quality of supply so as to meet the improved amenities which consumers will require as they use precision apparatus such as synchronous-motor clocks, wireless and television sets, etc. Expenditure of the second class will yield a return, but with a time-lag that varies with the progressiveness of the undertaking and its ability to reduce charges progressively so as quickly to bring into full use the apparatus on which expenditure has been incurred.

In general, the unremunerative class of expenditure is largely beyond the control of individual supply authorities, but as regards the second class of expenditure it is felt that the whole question of the amount of yield and the period which must elapse before the expenditure becomes remunerative is bound up completely in the future development of tariffs and charges, as is the third factor under consideration, viz. the average charge per unit sold.

Summary of the Relationship between Factors (a) and (b).

The relationship between the various factors affecting cost and charges can be summarized in a concise manner by means of the statement which was set out earlier, i.e.

(Annual return required on capital) $\propto$
(Units sold per £ of capital) ×
(Average revenue received per unit sold)

When discussing the relationship between the units sold (consumption) and the average revenue received per unit sold (price), it was stated that electricity is a commodity for which increased demand is accompanied by a proportionately reduced cost of production, within certain limits. These limits may be indicated quantitatively by means of the factor introduced by Mr. Kennedy and Miss Noakes—the units sold per £ of capital. If the various supply undertakings are considered, first in groups and then for the whole industry, the statement shown above indicates the importance of attaining to the "medium" or "high" rate of consumption so as to obtain a condition of "expanding demand." Until this condition is reached, a reduction in charges will not cause a marked increase in consumption, with the result that the product of the two factors—"units sold per £," and "average revenue received per unit"—will fall and the average return on capital will be insufficient to meet the costs of providing supply. When a condition of "expanding demand" is reached, a small decrease in the charge causes a marked increase in consumption, with the result that the units sold per £ increase in a greater proportion than the reduction of revenue, and the product of the two factors will increase (assuming that capital expenditure does not increase proportionately, as would not be likely when a high value of "elasticity of demand" occurs). In this manner, the annual return obtained on capital will be greater than the cost of providing supply, and a condition of surplus is reached which (as with Joint Electricity Authorities) should be returned to the consumer in the form of reduced charges; these reduced charges, in their turn, will cause a further stimulation in demand so as to break the "vicious circle" referred to earlier in the paper.

It is, however, necessary to consider the conditions which allow a reduction in charges to be made, since it has been premised that a reduction in charge must precede an increase in consumption, in the medium and high ranges of consumption. Fig. 5 shows that the consistent reduction since 1921 in the total cost of supply has been due almost entirely to the consistent decrease in the cost of generation, but that we are approaching a limiting value for generation costs. We cannot, therefore, rely in the future upon a decreasing cost of generation, and if a continuous reduction of charges is to be carried out in the future the cost of distribution must be reduced. Table 9 does not show any sign of a steady and progressive decrease in any of the component costs of distribution (except for the item of "repairs and maintenance") but rather that distribution costs are unstable, with a strong possibility that in any year the component of capital charges may rise, owing to a large amount of capital expenditure being incurred which may be temporarily or permanently unremunerative.

As has been pointed out by other authors,* this is the very real problem which faces the supply industry. It has been premised that a reduction of charge must precede an increase in consumption into the high range and that this reduction of charge must be accomplished by reducing the cost of distribution. The cost of distribution per unit sold can only be decreased if the consumption "per £ of annual distribution cost" increases (see col. 8, Table 9); if the average rate of consumption decreases, the cost per unit sold will rise. We are, however, most probably at a stage where the average rate of domestic consumption is decreasing, and, simultaneously, the cost of providing supply is becoming stationary. An increase in consumption for power purposes is not likely to improve the position for some years, as the revenue from power supplies is probably insufficient fully to cover its own fixed charges of distribution (col. 5, Table 7).

This stalemate condition is obviously dangerous as it may result in an increase of distribution costs, which are already unstable, and may thus commence a period of retrogression in consumption; it is the point at which the "vicious circle" is caused. Mr. Kennedy and Miss Noakes have shown how an amalgamation of undertakings would tend to reduce the average costs of distribution—their conclusion is illustrated in Table 6 and Fig. 4 of this paper. But in the author's view the reduction in cost which would undoubtedly result from the amalgamation would give only a temporary stimulus to consumption. The more permanent stimulus must be obtained by increasing the average rate of domestic consumption into the "medium" and then into the "high" ranges of consumption so that, with the "expanding demand" which would result, a small reduction in charge would result in a marked increase of consumption. It can be shown that the prices per unit which consumers will pay for a given amount of electricity in the "medium" and "high" ranges vary within much smaller limits than for the given amounts of electricity in the "low" range (see Fig. 7). It is clear, therefore, that a condition requisite to obtaining a general increase in consumption into the high range for all undertakings is that their tariffs and charges shall be made uniform. The amalgamations suggested by Mr. Kennedy and Miss Noakes would be of further benefit in the sense that they would assist in reducing the large number of tariffs and charges now in force.

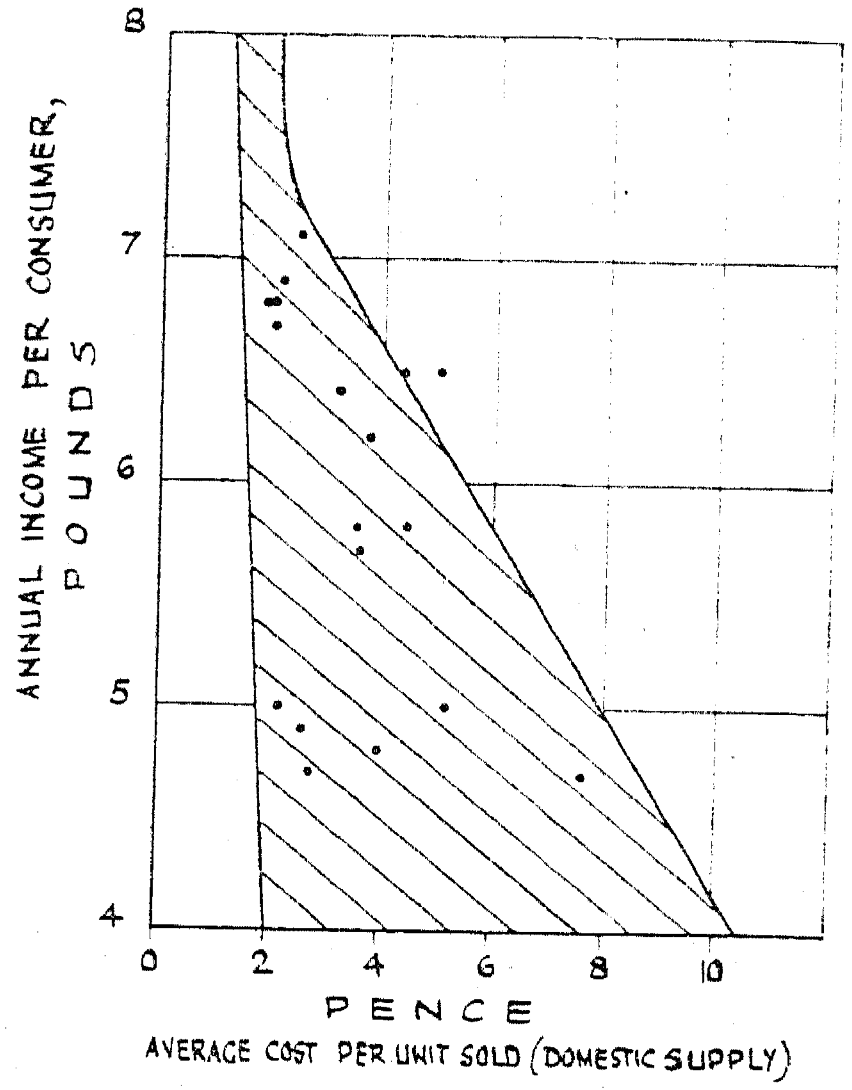


Fig. 7.—Graph showing the close relationship between annual income per consumer and average price per unit, as price is reduced. (Data from cols. 7 and 10, Table 2.)

It will be seen, therefore, that uniformity in tariffs and charges represents a most important factor in determining the increase in average consumption, and a brief examination is now made as to the means by which the uniformity may be reached.

TARIFFS AND CHARGES FOR ELECTRICITY

A tariff is nominally a list of articles or a price schedule but is considered as a *basis or method of charge* for electricity supply. The payment which has to be made is related to a quantity defined in the tariff, e.g. per unit, per consumer, etc., and represents the *charge* made for electricity. This definition has been given because of the different connotations which are current with regard to these items. The effect of the factors discussed earlier is now considered in relation to tariffs and charges.

Consideration of the most Suitable Tariff.

Any movement which takes place with a view to coordinating tariffs and charges should have as its ultimate aim a single tariff and charge, common to all consumers. Experience will show how far such an ideal is wise or practicable, and any examination of a unified tariff and charge at this stage must be largely theoretical. There are, however, indications which lead to the conclusion that the conditions which would permit of a large measure of unification are already in existence.

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* See, for instance, *Journal I.E.E.*, 1936, vol. 78, p. 1.

The previous portion of the paper has shown that the most suitable tariff for domestic consumers must permit of a graded cost per unit, the cost varying according to the annual consumption in the manner indicated approximately in Fig. 3. This would lead either to a " block " tariff or a multi-part tariff, and, since the variation in charge could vary in the required manner by the use of either of these tariffs only the multi-part tariff has been considered for the purpose of discussion.

The general conditions with which a domestic multi-part tariff should comply have been stated in a most succinct manner by the 1930 Committee on Tariffs. The following is an abstract from their Report:—

" *Conditions with which a Domestic Multi-part Tariff should comply.*

(*a*) The aggregate amount of the individual fixed charges should provide sufficient revenue to cover all the standing charges incurred in giving the supply to the consumers on the multi-part tariff.

(*b*) The basis adopted for assessing the fixed charge should be available to consumers, and should not be subject to adjustments which are not disclosed.

(*c*) The ' secondary ' or unit charge should be as low as practicable.

(*d*) The tariff should be simple in character, readily applicable to any type of domestic consumer, and equitable both to consumers and the Supply Authority.

(*e*) It should involve the smallest possible expenditure on the one hand by the Supply Authority on apparatus (e.g. meters) and on the other hand by the consumer on wiring.

(*f*) It should not entail either periodical or unexpected visits of inspection to the consumers' premises; consequently, in allocating the fixed charge regard should be had to the consumers' premises as a whole.

The expression ' Standing Charges ' as used in this Report signifies those charges which have to be incurred by the Supply Authority independently of the amount of output or sale of electricity and includes capital charges (or, in the case of local authorities, loan charges), rent, wages, the " ready to serve " or " service " charge, the cost of apparatus (e.g. meters), maintenance, meter-readings, accountancy, etc."

The Committee consider (see Para. 67 of their Report):—

" As it is not practicable for the Supply Authority to ascertain the effective demand of each domestic consumer (i.e. by taking into consideration the nature, extent and period of his uses of electricity) the only course open to the Supply Authority in order to arrive at an equitable fixed charge, is to divide the proportion of the standing charges due from the whole body of domestic consumers on the multi-part tariff according to some reasonable basis. In the opinion of the Committee the Supply Authority is justified in taking this course as the diversity factor of the domestic load is such that it can be ' averaged out ' in that manner with fairness to individual consumers."

Uniformity in tariffs is only the first step towards the greater need of uniformity in charge. Consideration of the curve of " value " of electricity to the domestic consumer (Fig. 3) will show that when consumption enters the " high " range the permissive variation in the charge per unit becomes much less than for consumption in the " medium " or " low " ranges.

If the average rate of annual consumption is to be increased from the present figure of approximately 800 units to a minimum of 2 000 units the paramount importance will be realized of obtaining a suitable secondary charge *which must be uniform for all undertakings.* The amount of this charge has been shown to be approximately 0·5d. per unit for domestic consumers (see Fig. 3).

Further consideration of the nature of the modern fixed charge required from domestic consumers shows that it is becoming more in the nature of a service charge which is independent of a consumer's consumption in units. In the low and medium ranges of consumption, therefore, the fixed charge will be the predominating ingredient of the total cost per unit paid by a domestic consumer, but as consumption enters into the high range the secondary charge approximates more closely to the total cost per unit paid for the supply.

The amount of the fixed annual charge is therefore only important when consumption is in the low or lower-medium stage. The large number of types of fixed charge now in use is tending to be reduced but, in the opinion of the author, none of the methods which base the fixed charge upon some feature peculiar to the consumer is likely to be successful in achieving a high rate of consumption. The result of these methods is to cause consumers who may have the same annual consumption and similar habits of using electricity, to pay different amounts for their electricity. A large amount of the present bewilderment and suspicion which is in the minds of consumers is due to the wide variation in charge which results from the large number of the existing methods of deriving the fixed charge. There is good reason, therefore, for suggesting that any steps which are taken to achieve uniformity in tariffs should be made with a view to obtaining ultimately the same amount of fixed annual charge from each consumer. This would satisfy conditions (*d*) and (*a*) mentioned earlier (in the abstract from the 1930 Committee on Tariffs), and two factors which are operating in modern supply so as to make a uniform fixed charge possible, and desirable, will now be briefly considered.

The Influence upon Tariffs of an Increasing Proportion of Fixed Charges.

Fig. 8 illustrates the steady increase of the fixed charges of providing supply as an ingredient per unit sold; it will be seen that the percentage of fixed charges due to distribution costs was 39·7 in 1922–23 and 50·6 in 1932–33. (The costs of distribution are considered here as being fixed with only a very small, and almost neglible, proportion of working costs.) The decrease in the capital charges of generation during the year 1934–35 suggests that there is a possibility of a further slight decrease in this item in future years. The future tendency of the distribution costs is not so easy to forecast. Although generation, under the operations of the Central Electricity Board, is now sufficiently co-ordinated to permit of a reasonable knowledge of the trend of capital expenditure for several years ahead, the position with regard to distribution is much more obscure, and the effect of unremunerative capital in affecting future costs can only be assumed. The earlier study as to the stationary, or declining, rate of domestic consumption could lead quite reasonably to the assumption that the proportion of total cost due to distribution may increase for several more years, until a reasonable measure of uniformity in tariffs and charges is obtained and consumption increased thereby.

The influence of the change in the proportion of fixed to working costs is bound to affect seriously the nature of the correct modern tariff for the domestic consumer. It will mean that for every unit sold a decreasing proportion of the total charge per unit will be required to cover working costs, and an increasing proportion will be required to meet, firstly a purely " consumer " charge, and secondly the capital charges of generation. So far as the domestic consumer is concerned, the latter charges are ceasing to be represented correctly by the imposition of a " kilowatt " charge, because of the increasing importance of diversity and the decreasing importance of load factor. We appear to be approaching fairly rapidly to a position in which tariffs for domestic electricity consumers must approximate more closely to those of water supply, where the smaller consumer is charged an annual sum independent of his normal consumption of water. Fig. 8 suggests that electricity consumers in the low and lower-medium categories of consumption should pay an annual amount, most of which is required to cover fixed charges, and a very small additional amount to cover the working costs.

If the author is correct in assuming that the supply industry may shortly be faced with the possibility of a retrogression in the averaged rate of domestic consumption and a consequent increase in costs, and that a large measure of unification of tariffs and charges is the only effective way of stimulating consumption so as to decrease these costs, it is important that the nature of the most suitable domestic tariff and charge should be determined as soon as possible. Movements of thought as regards tariffs are notoriously slow, and some undertakings have not yet adopted the multi-part tariff basis suggested by Dr. Hopkinson as long ago as 1892. The present position of tariffs is particularly unfortunate because it consists of a mid-way position between the " kilowatt " basis of fixed charge, applicable only to the earlier days of distribution, and the purely " consumer " basis which has arisen due to the rapid development of distribution. Thus we have the " rateable value " and " floor area " tariffs, neither of which is equitable to the consumer and which should be looked upon only as interim and not final forms of tariffs.

The formulation by Dr. Hopkinson of the principle of multi-part costing and tariffs was one of the most important stages of progress in the history of electricity supply. The application of the principle to tariffs has, however, been singularly difficult and has caused a wide variety of tariffs to be formulated, each of which has approximated to Dr. Hopkinson's principle in varying degree. The chief effect has been to cause supply engineers to become satisfied with a system of charging in which the amount received annually or quarterly from each consumer has varied widely; for a given undertaking the variation has then been made greater by virtue of each undertaking adopting its own basis of charging without reference to those of other undertakings. We have reached, by tradition, a position in which we have the anomaly of two consumers, with the same annual consumption, paying different amounts, and this is regarded as a rational condition of supply.

The earlier discussion has shown that it is only in the low range of consumption that the annual income from consumers varies within wide limits at a given price per unit, but that it approaches uniformity in the higher ranges (see Fig. 7). A policy of tariff construction designed to encourage domestic consumption and envisaging an advance into the high range exceeding 2 000 units, must endeavour to make more uniform the annual amounts paid by consumers having equal consumption. It is difficult to justify any of the present methods of multi-part tariffs which result in a different fixed charge for each consumer based upon some feature related to his house or his physical possessions, except as a pseudo-scientific application of Dr. Hopkinson's principle and as a very arbitrary means of obtaining sufficient income from consumers to meet the costs of providing supply.

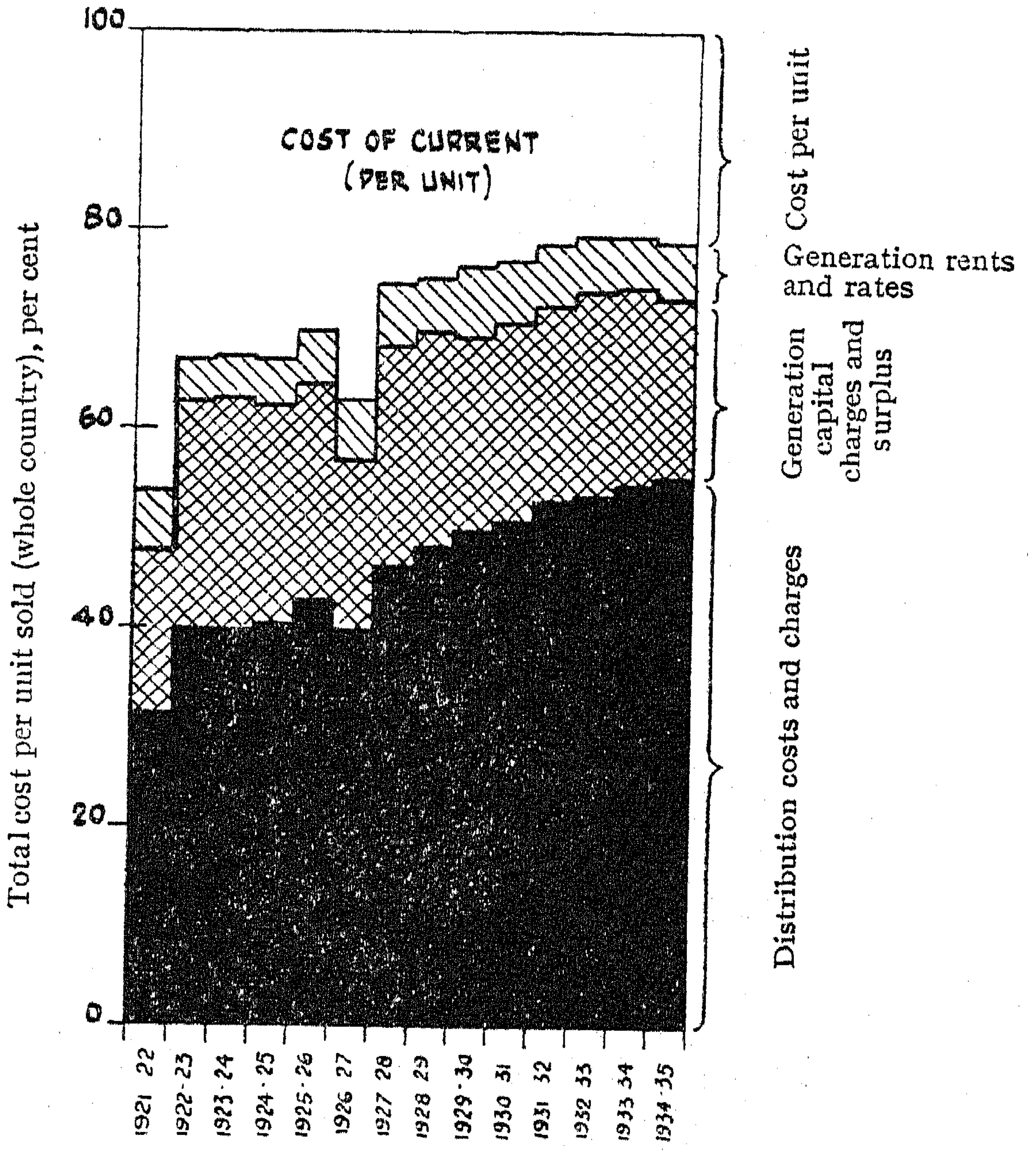

Fig. 8.—Illustration of the increasing proportion of cost per unit sold, due to fixed charges.

So far as the domestic consumer is concerned, it is now suggested that for large modern undertakings the original Hopkinson definition of the fixed charge has ceased to be correct as a basis of fixed charge, and that we must now consider this matter in the nature of a " consumer " charge. Dr. Hopkinson laid down that there must be a "fixed charge per quarter proportioned to *the greatest rate at which a consumer may ever use electricity.*" It has therefore been usual to assume that we must charge a domestic consumer a fixed charge which must be related directly, or indirectly, to his highest kilowatt demand. This ignores the much greater distribution system fixed charges which are in many cases independent of the kilowatt demand on the system and are related directly to the number of consumers on the system. But the relation between the fixed annual charges for distribution and the fixed annual charges for generation were immensely different in 1892 when Dr. Hopkinson formulated the basis of a multi-part charge, from the relations which exist to-day. Even presuming the greatest prescience on the part of an engineer of that time, it is unlikely that he could foresee the enormous subsequent development of electricity distribution.

The author suggests that modern developments compel us to reconsider the basis to be adopted for charging, certainly domestic consumers, if we are to retain with equity the two-part system of charging for electricity. Even if the inference were correct that we should base the fixed charge in any manner upon the consumer's highest kilowatt demand, it is neither practicable accurately to determine this charge nor to obtain the consumer's approval to it. The correct kilowatt charge of each consumer will depend upon the time of demand, diversity of the consumer and of the group of consumers, voltage of supply, etc., and, in fact, it is not possible of exact computation.

The Influence upon "Annual Consumer Cost" of an Increasing Number of Consumers.

For each consumer connected to existing mains a certain minimum amount of capital expenditure is incurred for the service, meter, etc. The effect of the connection, however, is to reduce the average value for the whole undertaking of the capital expenditure per consumer and also to reduce the average "consumer cost" in respect of other fixed charges such as management, accountancy, advertising, etc., which, in total, comprise the greater proportion of the costs of distribution. Whilst these fixed charges of distribution are incurred independently of the consumption, they are to a great extent dependent on the number of consumers. It is for this reason that a fixed annual "consumer charge" is suggested for consideration as the correct modern basis of fixed charge. It is more equitable and practicable to impose than a fixed charge based on kilowatt demand, size of house, rateable value, or other criterion which is related to the kilowatt charge.

The effect upon the value of averaged capital expenditure per consumer by the connection in recent years of large numbers of domestic consumers, cannot be estimated with any accuracy owing to the lack of knowledge of the proportion of capital which must be allocated between power and domestic consumption. But it is possible to indicate the approximate nature of the reduction in average annual "consumer cost" by the method adopted in deriving the values in Table 13. In order to obtain the data shown in that Table the units sold for domestic and power supplies, respectively, were multiplied by the distribution cost per unit shown in col. 6, Table 9, for each year. The resulting annual cost of distribution, allocated between power and domestic supplies, was then divided by the estimated number of power and domestic consumers shown in cols. 4 and 5, Table 14, so as to give the "consumer costs" of distribution shown in cols. 2 and 3, Table 13. The effect of an increasing number of consumers in reducing the average capital cost per consumer can be observed indirectly from this Table. An explanation may be required here with regard to the statement that an increase in the number of small consumers had caused a reduction in the efficiency of distribution owing to the reduced yield on capital which resulted from their connection. It will be seen from Table 13 that, although each new consumer on the route of existing mains will reduce the average "consumer cost" for the whole country, that consumer will be unremunerative if his annual payments are less than

Table 13

Annual "Consumer Charge" obtained by allocating the Costs of Distribution between Domestic and Power Consumers in proportion to Domestic and Power Consumption in each year and Secondary Charge equal to Unit Cost of Generation

Years	Consumer cost of distribution			Cost of generation (per unit sold for all purposes)
	Domestic consumers	Power consumers	Total consumers	
1	2	3	4	5
	£	£	£	d.
1927–28	2·57	22·8	7·26	0·832
1928–29	2·52	22·6	6·80	0·748
1929–30	2·48	23·4	6·45	0·698
1930–31	2·44	23·4	5·84	0·676
1931–32	2·36	23·5	5·54	0·640
1932–33	2·23	23·2	5·1	0·616
1933–34	2·07	25·3	4·9	0·570
1934–35	1·86	24·4	4·3	0·531
1935–36				

Tariffs and Charges resulting from Application of above Data, for the Year 1934–35

	Tariff		Total cost per unit sold	
	Annual fixed charge per consumer	Secondary cost per unit sold	By application of theoretical tariffs	Actually obtained
			pence per unit sold	
Power consumers	£24·4 per consumer +	0·531d. per unit	1·13	0·69
Domestic consumers	£1·86 per consumer +	0·531d. per unit	1·14	2·13

the annual "consumer cost." But the importance will be observed of encouraging consumers to take supply who are already on the route of existing mains, and of following this policy by the formulation of a tariff and charge which will cause a gradual increase in consumption until a condition of "elastic demand" is reached for each consumer. The increase of capital that will ultimately be required to provide larger mains will then be off-set by the rapid increase in the "units sold per £."

The data given in Table 13 are of interest as indicating the reasons which make impracticable under present conditions any uniformity in tariff and charge on an equitable and satisfactory basis. In effect, Table 13 comprises a series of annual two-part tariffs for domestic

Table 14

DERIVATION OF VALUES OF THE AVERAGE FIXED ANNUAL "CONSUMER" CHARGES WHICH APPLY TO THE TOTAL SALES FOR THE WHOLE COUNTRY WHEN THE SECONDARY CHARGE IS CHOSEN AT 0·5D. PER UNIT

Year	Total units sold for—		Estimated consumers		Total revenue received for—		Revenue at 0·5d. per unit sold for—		Fixed consumer charge, i.e. remaining revenue (Col. 6 less Col. 8, and Col. 7 less Col. 9) divided equally between estimated consumers	
	Power	Domestic	Power	Domestic	Power	Domestic	Power	Domestic	Power	Domestic
1	2	3	4	5	6	7	8	9	10	11
	millions	millions	millions	millions	£ millions	£ millions	£ millions	£ millions	£	£
1927–28	4 537	1 708	0·6	2·0	17·68	24·14	9·45	3·56	13·9	10·3
1928–29	4 926	2 036	0·64	2·35	17·64	25·86	10·28	4·24	10·05	9·18
1929–30	5 408	2 344	0·66	2·81	18·42	27·96	11·27	4·88	10·9	8·2
1930–31	5 371	2 744	0·68	3·33	18·14	30·49	11·13	5·72	10·2	7·47
1931–32	5 435	3 072	0·70	3·95	17·97	32·47	11·32	6·4	9·4	6·62
1932–33	5 693	3 469	0·73	4·64	18·33	34·78	11·88	7·22	8·8	5·95
1933–34	6 391	3 916	0·73	5·38	19·52	37·13	13·32	8·16	8·5	5·4
1934–35	7 285	4 535	0·75	6·15	20·93	40·23	15·18	9·46	8·28	5·0
1935–36	8 250	5 505	0·85	6·85	22·66	44·07	17·20	11·52	6·33	4·75

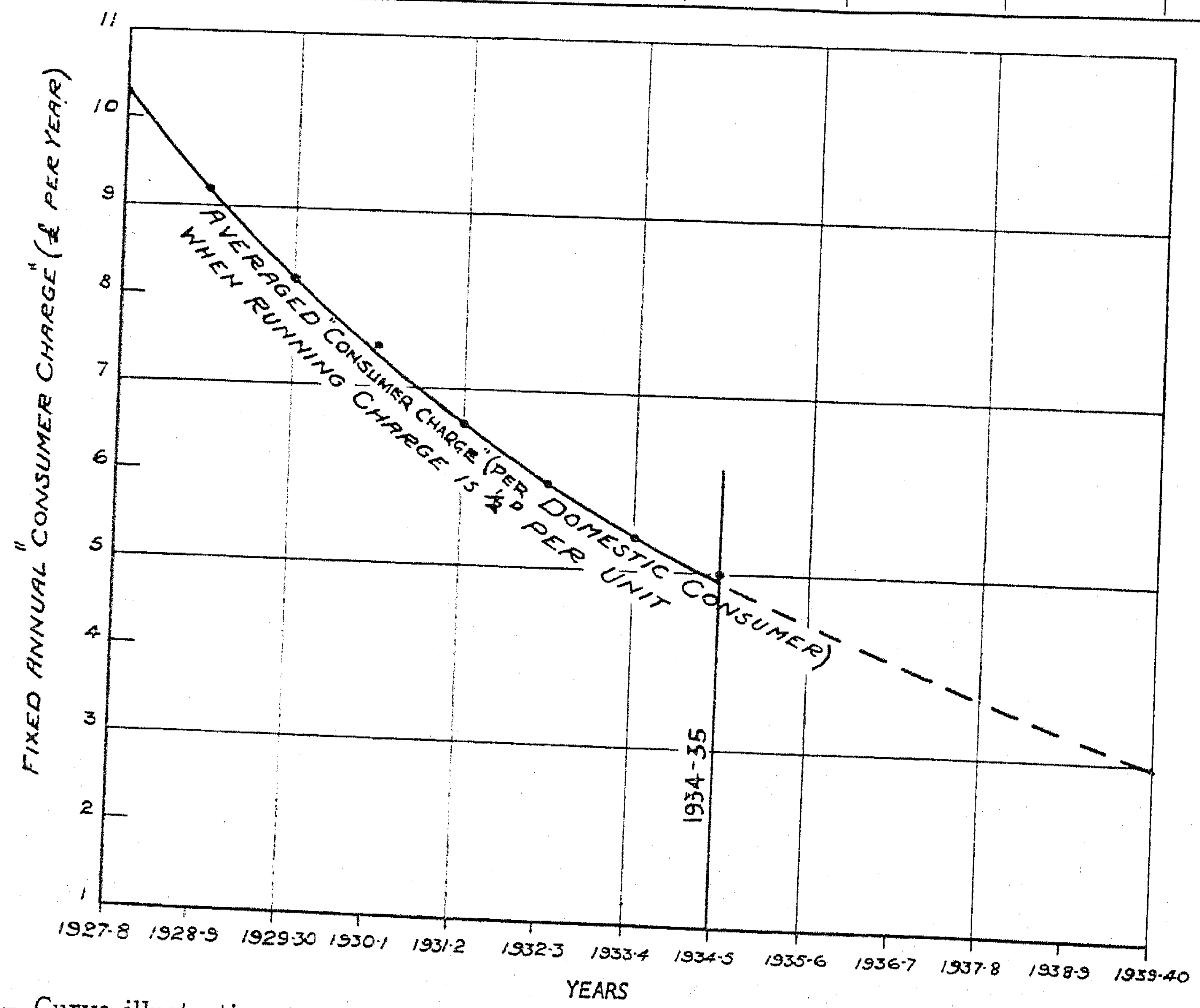

Fig. 9.—Curve illustrating trend of averaged fixed annual "consumer charge" for whole country, as derived in Table 14.

and power consumers. The tariff consists of an annual "consumer charge" which is equal for all consumers, and a secondary charge which is equal to the generation cost per unit. The fixed annual "consumer charge" has been obtained by allocating the total annual costs of distribution (considered here as fixed costs) between domestic and power consumers, in proportion to the amount of consumption for domestic and power supplies, respectively, and then dividing the resulting amounts of money equally between the estimated domestic and power consumers. The average cost per unit which would result from the application of a tariff devised as above is shown at the bottom of Table 13, and would obviously result in an impracticable position of charging. The method of allocating the charges in Table 13 is, however, not wholly untenable and serves to illustrate the earlier suggestion that domestic supplies are bearing an undue proportion of the costs of distribution.

Table 15

VALUE OF ANNUAL "CONSUMER CHARGE" FOR GROUPS OF LOCAL AUTHORITY UNDERTAKINGS IN TABLE 6, WHEN SECONDARY COST IS FIXED AT 0·5D. PER UNIT. (BASED ON UNITS SOLD FOR ALL PURPOSES AND TOTAL CONSUMERS)

Group number	Annual output (per undertaking in group)	Charges resulting from theoretical 2-part tariff applied as in Table 14 but to total units sold and total consumers	
		Annual consumer charge	Secondary cost per unit
	1	2	3
	millions of units		
1	0–1	£4·9	0·5d.
2	1–2	£4·1	0·5d.
3	2–3	£4·4	0·5d.
4	3–4	£5·7	0·5d.
5	4–5	£5·4	0·5d.
6	5–10	£4·4	0·5d.
7	10–15	£4·3	0·5d.
8	15–20	£4·8	0·5d.
9	20–25	£4·7	0·5d.
10	25–30	£4·5	0·5d.
11	30–40	£4·6	0·5d.
12	40–50	£4·5	0·5d.
13	50–100	£5·5	0·5d.
14	100–200	£5·2	0·5d.
15	200–300	£3·8	0·5d.
16	300–400	£4·6	0·5d.
17	400–600	£6·5	0·5d.

Table 14 has been prepared by accepting the existing allocation of distribution costs between the power and domestic loads and considering the annual income received in each year from 1927–35 from the two classes of supply. The secondary cost of 0·5d. per unit, which was shown in Fig 3 to be the possible maximum secondary cost for a modern two-part domestic tariff, has been adopted as the secondary charge for power and domestic supplies and the revenue which would accrue from the secondary charge as shown in cols. 8 and 9. The difference between the actual revenue received (and shown in cols. 6 and 7) and the hypothetical revenue from the secondary charge (as shown in cols. 8 and 9) has been divided equally between the estimated number of consumers so as to form an arbitrary and equalized annual "consumer charge."

The decreasing nature of the "consumer charge" which results for domestic consumers is of some interest as showing the effect of connecting an increasing number of consumers and has been plotted as a graph in Fig. 9 with the curve continued so as to obtain the hypothetical value of the domestic "consumer charge" for 1939–40. It will be seen from Fig. 9 that it can be anticipated that in three more years the averaged cost of providing supply to domestic consumers would be met if the average annual sum of £3 were obtained from each consumer and all units were supplied at 0·5d. It will also be seen that the adoption for power supplies of the same uniform running charge of 0·5d. per unit would result in an annual "consumer charge" to each power consumer of approximately £8.

Table 16

VALUE OF ANNUAL "CONSUMER CHARGE" PER DOMESTIC CONSUMER FOR GROUPS OF UNDERTAKINGS IN TABLE 2, WHEN SECONDARY COST IS FIXED AT 0·5D. PER UNIT. (BASED ON UNITS SOLD FOR DOMESTIC PURPOSES AND ESTIMATED NUMBER OF DOMESTIC CONSUMERS)

Group number	Annual output (per undertaking in group)	Charges resulting from theoretical 2-part tariff applied as in Table 14, but to domestic consumption and estimated domestic consumption	
		Annual consumer charge	Secondary cost per unit
1	2	3	4
1	0 to 0·1	£6·64	0·5d.
2	0·1 to 0·2	£4·82	0·5d.
3	0·2 to 0·3	£6·2	0·5d.
4	0·3 to 0·4	£3·9	0·5d.
5	0·4 to 0·5	£5·1	0·5d.
6	0·5 to 0·75	£5·5	0·5d.
7	0·75 to 1·0	£5·05	0·5d.
8	1·0 to 1·5	£5·67	0·5d.
9	1·5 to 2·0	£4·95	0·5d.
10	2·0 to 3·0	£5·4	0·5d.
11	3·0 to 5·0	£4·0	0·5d.
12	5·0 to 7·5	£5·77	0·5d.
13	7·5 to 10·0	£3·32	0·5d.
14	10·0 to 17·5	£4·92	0·5d.
15	17·5 to 25·0	£5·76	0·5d.
16	25·0 to 37·5	£7·38	0·5d.
17	37·5 to 50·0	£6·63	0·5d.
18	50·0 to 100	£5·05	0·5d.
19	100 and over	£5·04	0·5d.

In order to test the validity of this arbitrary tariff and charge for the smaller undertakings, Tables 15 and 16 were prepared. A remarkable similarity of "consumer charge" is shown in Table 15 for each of the groups of local authority undertakings. Table 16 relates only to revenue from domestic supplies and the estimated number of domestic consumers, but it gives a further confirmation of the indications which were given in Fig. 2, that the average charge to domestic consumers tends to rise with undertakings with total annual sales of electricity exceeding approximately 50 million units.

Practical Steps towards Uniformity of Tariffs and Charges.

The previous discussion on tariffs was largely theoretical and was intended to indicate the conditions in the supply industry which are assisting the movement towards uniformity in charging for electricity. The ultimate uniformity will almost certainly require to be reached by a series of experiments designed to simplify gradually the complex position which has now been reached in the supply industry.

A knowledge of the operation of supply undertakings shows that tariff formation is essentially a matter of compromise, with the need constantly in mind that the annual revenue to be received must balance the annual cost of providing supply. This need accounts to a great extent for the multiplicity of tariffs. When, under the pressure of competition or intimidation, a new tariff or charge is introduced, it is generally so designed as to affect a minimum number of consumers and thereby to cause as small an unbalancing as possible of the delicately interwoven consumers' revenues. As far as possible, it is designed to give only a fractional reduction in cost and we are continually being led into a position which tends towards a separate tariff for each of the many classes of consumers, so following the rule established by manufacturers and traders. Tariffs and charges are, therefore, based almost completely on expediency; the number is increasing daily and the need to derive a rational basis of cost is subordinated to the principle of getting as much as possible from each consumer.

Most engineers would agree that steps should be taken to achieve more uniformity in tariffs and charges, and we may ultimately reach a position, by evolutionary methods, in which the present large number of tariffs and charges are reduced, but it is unlikely that any large measure of unification will be achieved until an authoritative body such as the Electricity Commissioners indicates the base or bases which have to be adopted and make these bases compulsory after a given period from their publication.

The author is convinced that the adoption of a standard tariff, common to all undertakings, is essential to obtain an increase in the rate of domestic consumption, and there is every reason to think that this desideratum will not be achieved by voluntary agreement. The first step which is suggested as being necessary to obtain any large measure of unification is that the formation and the imposition of tariffs should be the sole responsibility of an authoritative central body possessing executive powers. This would involve the need for the central authority to assume responsibility for any financial loss which might accrue to an undertaking owing to the imposition of the new tariff basis. It is also probable that the authority would require to guarantee the undertakings against any annual loss that might occur, temporarily, on account of increased capital expenditure for new mains or services or the increase in capacity of those already in use. In the first stages of such a scheme the whole country would, presumably, be zoned and a standard series of fixed and secondary charges instituted which would approximate to the charges already in use by a majority of the consumers in each zone, with an approach towards a uniform secondary charge of 0·5d. per unit as far as possible in the initial stages.

It will be seen from Fig. 2 and Table 2 that, although many undertakings would be affected as the result of the above proposal, the number of consumers who would suffer any large alteration in charge would be small, in the event of zoning a number of small undertakings with one large undertaking. A precedent exists for the carrying out of part of the procedure suggested above, in the operation of the Central Electricity Board in instituting what may shortly prove to be a common wholesale tariff and charge for all undertakings.

The steps that should be taken to ensure uniformity of charges must be taken by an authoritative body such as the Electricity Commissioners, who would require to have power to impose their decisions upon all supply undertakings. The Electricity Commissioners would require, firstly, to decide on the basis of tariff; this basis should then be adopted by all undertakings and offered exclusively after a period of, say, 3 years from a given date. A two-part tariff or a "stepped block" tariff is suggested as the correct basis, and the secondary charge, or unit cost, should be common to all undertakings for all except special cases of competitive supplies or "off-peak" loads. The type of fixed charge would also require to be uniform for all undertakings, but the amount of the fixed charge on this uniform basis should be left to the discretion of the undertaking and would require to be varied for several years for each class of consumer. An alternative method of charging by means of a "stepped block" tariff would be valuable in the early stages so as to ascertain the relative popularity of each method, but the lowest "block" charge under the stepped tariff should be the same as the "secondary charge" under the two-part tariff.

The adoption by all undertakings of a standard secondary charge is not likely to disturb present conditions seriously. Many undertakings already have a two-part tariff in operation (see Table 17), and the various secondary charges are not widely different, as indeed they must not be if the two-part tariff is to prove effective. The alteration required to permit of standardization generally at, say, 0·5d. per unit, would not therefore seriously disturb present revenues.

The balance of revenue would require to be met from the fixed charges to consumers. It would therefore be necessary to permit fixed charges to be varied, for instance by making a consumer's fixed charge equal to the balance of his account for the previous year, after deducting the amount obtained from the secondary charge. In future years, reductions in price should be made only on the higher fixed charges so as ultimately to reduce these to a common low level. The consumer with very low consumption, who is at present the cause of annual loss to an undertaking, would tend to use more units and this would lead ultimately to a uniform fixed charge for domestic consumers. Two main effects would be produced if a scheme of the nature proposed above were adopted nationally:—

(1) The effect upon consumers of the knowledge that the secondary charge per unit was the same for all undertakings would be to remove many suspicions and doubts from their minds as to the integrity of supply undertakings. The consumer would talk and think in terms of the standard secondary charge per unit. He would still object to the wide variation in the monetary amount of the fixed charges which would apply for some time but would realize that a larger measure of unification was being reached each year.

(2) The consumption of electricity throughout the country would be greatly stimulated. This is shown at present in all cases where a two-part tariff has been introduced. Those undertakings which now have low flat rates and no two-part tariffs would require to install a large quantity of new mains and plant to cope with the increasing consumption which would undoubtedly ensue.

Table 17

NUMBER OF HOUSES AND CONSUMERS TO WHOM A TWO-PART DOMESTIC TARIFF IS AVAILABLE. (Data taken from E.D.A. Publication No. 1310: "Rehousing with the aid of electricity.")

Secondary cost per unit under two-part domestic tariff	Number of houses in areas of supply	Per cent	Number of connected consumers	Per cent
0·5d. and under	4 609 294	40·5	2 759 283	44
Over 0·5d. and up to 0·75d.	3 356 476	29·5	2 028 239	33
Over 0·75d. and up to 1d. ..	2 494 499	22	1 095 874	18
Above 1d. ..	936 274	8	317 116	5
Total ..	11 396 543	100·0	6 200 512	100

The author would emphasize, in conclusion, that space does not permit of a description of the progressive experiments in tariffs and charges which have been made by certain undertakings who are developing their supply on active lines. The purpose of the paper has been chiefly to indicate the modern tendencies in the supply industry which make imperative a large increase in domestic consumption, and also to indicate in a theoretical manner the conditions which already exist to permit of a large measure of uniformity in domestic tariffs. For the same reason the question of power supplies has only been considered in the light of their effect upon domestic consumption and charges.

CONCLUSIONS

The increased rate of consumption of certain domestic consumers is neutralized by the connection in recent years of a large number of domestic consumers with an annual consumption below the average. There are reasons for assuming that many of these latter consumers have a constant annual consumption and are not progressively increasing the uses which they make of electricity.

In order to increase their average consumption it is necessary to offer to them a price which must be less than 2½d. per unit; a reduction in price which does not fall below this figure will not result in a marked increase of consumption. A reduction in price which does not fall below 2½d. per unit is also uneconomical to the supply undertaking, as it has no appreciable effect in increasing consumption to a degree which will permit of an appreciable reduction in the cost of providing supply.

The supply industry, when considered as a whole unit, is approaching a critical position in which the cost of providing supply may tend to increase, owing to a stationary rate of domestic consumption, and this condition may, in its turn, produce a retrogression in the rate of domestic consumption. There is an increasing rate of contribution by power supplies towards the distribution costs of the industry, but it is suggested that it may be some years before power supplies make their correct contributions towards the distribution costs and charges which are involved in providing power supplies, and it is therefore necessary to take urgent measures to increase the rate of domestic consumption.

The measures which are suggested, from the examinations made in the paper, are to reduce the cost at which domestic supplies are provided and to obtain a greater measure of uniformity in tariffs and charges than exist at the present time. It has been shown that when a consumer increases his consumption into the "high" range of consumption, i.e. 2 000 units per year as a minimum, the price per unit which he will pay approaches uniformity between undertakings. This is because there is a minimum amount of electricity which is becoming increasingly necessary to a consumer, e.g. for wireless sets and lighting, and he will use this amount whether the price charged per unit is, say, 4d. or 1s. But the succeeding amounts of electricity are of less value to a consumer, and the price must be reduced so as to be competitive with that of alternative forms of energy such as coal, oil, etc. Hence, as consumption increases, the price offered must approach increasingly closely to a uniform figure in whatever part of the country electricity is required.

Many of the smaller undertakings have an average cost of production which is above the critical value of 2½d. per unit. These undertakings are therefore unable to offer a sufficiently low price which would permit of a marked increase in consumption, except by incurring a financial deficit for, probably, a period of several years. Very few of the larger undertakings are supplying domestic consumers at an average price which is low enough to obtain the marked increase in consumption that would result in an equivalent lowering of the cost of production. These larger undertakings would probably incur a temporary deficit if they were to offer supply to *all* their domestic consumers, at a low enough price to permit of a general increase in consumption.

It is shown that a large measure of unification of tariffs and charges could be carried out without seriously disturbing revenues, but it is suggested:—

(*a*) That a larger amount of financial co-ordination is required between undertakings so that a pooling of revenues could be made. In this manner a greater amount of commercial risk could be taken in reducing charges in advance of the demand, than are permitted by the present individualistic system.

(*b*) That tariffs and charges should be governed and imposed exclusively by a single executive body which should consider tariffs and charges primarily from the view of the supply industry as a whole.

ACKNOWLEDGMENTS

Acknowledgments are made to those persons and sources from which many of the ideas in the paper have been derived. It is not possible to make detailed acknowledgments in most of these cases, but the author would express his obligation to all those with whom he has had the opportunity of discussing this question.

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APPENDIX

The Cost of Providing Supply to Domestic Consumers

A very complete analysis of the cost of supplying small domestic consumers in England was provided by Messrs. Woodward and Carne* in 1932. The portion of their analysis which relates to domestic consumers has been reproduced in Table 19, and values based upon recent experience for the larger undertakings have been inserted in the formulae. Table 18 has then been prepared in the manner illustrated on page 892 of the paper under consideration, but single consumers have been taken as examples and the simplest and cheapest case considered, where the consumers can be connected to existing mains and the capital expenditure required is that for meters and services only. The method of ascertaining the annual costs of supply is shown in Table 18 of this paper; the reader is referred to Messrs. Woodward and Carne's paper for further information of the method of estimating the capital costs per consumer, as illustrated in Tables 18 and 20.

Table 18

TABLE SHOWING ANNUAL COST OF PROVIDING SUPPLY AND COST PER UNIT FOR VARYING CLASSES OF CONSUMERS AND AT VARYING RATES OF RETURN ON CAPITAL

Class of consumer	Connected load	Annual consumption	Annual costs of supply					Total capital involved in providing supply	Annual revenue required and resulting cost per unit when return on capital is:—			
			Low voltage	High voltage	Units	Consumer charge	Total		5 per cent		10 per cent	
									Revenue	Cost per unit	Revenue	Cost per unit
1	2	3	4	5	6	7	8	9	10	11	12	13
	kW	kWh	£	£	£	£	£	£	£	d.	£	d.
1 house (6 rooms)	10·55	2 200	1·2	1·37	1·79	0·77	5·13	43·75	7·33	0·80	9·5	1·03
1 house (5 rooms)	1·6	130	0·111	0·155	0·105	0·77	1·141	15·94	1·94	3·6	2·7	5·08
1 house (4 rooms)	1·0	100	0·09	0·126	0·082	0·77	1·068	15·10	1·81	4·4	2·6	6·16
1 slot (3 lights) ..	1·68	78	0·07	0·01	0·063	0·46	0·603	15·57	1·46	4·5	2·24	6·90
1 public house ..	1·0	403	1·50	0·605	0·33	0·83	3·265	37·18	5·1	3·0	7·0	4·18
1 shop	0·1	80	0·24	0·168	0·065	0·83	1·303	24·70	2·55	7·6	3·8	11·4
1 sawmill ..	4·0	1 980	1·32	0·84	1·61	1·24	5·01	49·6	7·5	0·9	10·0	1·21

Method of deriving values in cols. 10 and 12 using 1st example of 6-roomed house:—

$$\frac{(\overset{\text{(Col. 12)}}{\text{Annual Revenue}} - \overset{\text{(Col. 8)}}{\text{Annual Costs}})100}{\underset{\text{(Col. 9)}}{\text{Total Capital Costs}}} = \text{percentage profit}$$

$$\text{In example, } \underset{\text{(Col. 12)}}{\text{annual revenue required}} = \frac{10 \text{ per cent} \times £43{\cdot}75 + 100 \times £5{\cdot}13}{100} = £9{\cdot}5$$

The formulae have also been used to ascertain the annual revenue and cost per unit which must be obtained from various classes of consumers in order to obtain a return on capital of 5 per cent and 10 per cent respectively. The values which have been derived are shown in Tables 18 and 20, cols. 10–13 and 6–9. Reference should be made to Tables 4, 5, and 7, of Messrs. Woodward and Carne's paper in order to obtain details as to the demand and other features of the consumers chosen in Tables 18 and 20 above.

The values in cols. 10 to 13 of Table 18, and in cols. 6 to 9 of Table 20, are based upon the return required

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* *I.E.E. Journal*, 1932, vol. 71, p. 852.

Table 19

TABLE ILLUSTRATING VALUES FOR LARGER UNDERTAKINGS OF COMPONENT COSTS OF PROVIDING SUPPLY TO CONSUMERS

Summary of Consumer Costs (Annual Charges)

Items	Prepayment consumers	Small-motor consumers	Quarterly domestic consumers	Quarterly shops, offices, etc.
Low-voltage Distribution:—	£	£	£	£
Repairs and maintenance: mains	0·05	0·13	0·15	0·08
Repairs and maintenance: house services	0·02	0·05	0·02	0·03
Repairs and maintenance: meters	0·04	0·10	0·04	0·06
Distribution consumer costs	0·11	0·28	0·11	0·17
Management, etc:—				
Management	0·02	0·02	0·02	0·02
Accountancy	—	0·05	0·05	0·05
Cashiers (prepayment consumers)	0·07	—	—	—
Cashiers (other consumers)	—	0·07	0·07	0·07
Statistical (excluding prepayment)	0·01	0·05	0·05	0·05
Testing department	0·03	0·03	0·03	0·03
Lighting department	0·20	—	0·20	0·20
Power department	—	0·50	—	—
Stationery and printing	0·004	0·04	0·04	0·04
Stamps and telegrams	0·005	0·05	0·05	0·05
Advertising	0·015	0·15	0·15	0·15
Management, etc.	0·354	0·96	0·66	0·66
Total consumer costs	£0·464	£1·24	£0·77	£0·83

Formulae Derived from Analysis of Costs (I.E.E. Journal, 1932, vol. 71, pp. 872–878).

Costs per annum:—	
(1) Per kVA of "effective demand" occurring during the period of heavy load on the high-voltage system and power stations	£3·00
(2) Per kVA of "effective demand" occurring during the period of heavy load on low-voltage networks	£2·1
(3) Per unit sold	0·195d.
(4) Per consumer:—	
(*a*) Domestic (quarterly accounts)	£0·77
(*b*) Shops, offices, etc.	£0·83
(*c*) Domestic (prepayment)	£0·46
(*d*) Industrial power consumers	£1·24
Capital:—	
(5) Per kVA of "effective demand" occurring during period of heavy load on the high-voltage system and power stations	£40·0
(6) Per kVA of "effective demand" occurring during the period of heavy load on the low-voltage networks:—	
(*a*) For use when considering existing supplies	£25·0
(*b*) For use when considering supplies involving low-voltage network extensions	£14·0
(*c*) For use when considering supplies involving expenditure on a complete network, including a new substation	£1·5

(7) Per consumer, as follows:—

Type of consumer	Factor (£ per consumer) to be used for:—	
	Supplies from existing mains	Supplies involving expenditure on mains
	£	£
(*a*) Standard domestic	5·5	0·7
(*b*) Shop, office, etc.	8·0	1·0
(*c*) Small works	12·0	2·0

Table 20

TABLE SHOWING ANNUAL REVENUE REQUIRED (AND THE RESULTING COST PER UNIT) FROM VARIOUS CLASSES OF CONSUMER

Consumer details			Cost of providing supply		Annual revenue and cost per unit of supply which must be obtained from the consumer when return required on capital expenditure is:—				
					5 per cent		10 per cent		
Number of lights (or rooms)	Connected load	Annual consumption	Annual*	Capital*	Annual revenue	Cost per unit	Annual revenue	Cost per unit	
1	2	3	4	5	6	7	8	9	
	W	kWh	£	£	£	d./kWh	£	d./kWh	
1	—	62	0·64	15·11	1·39	5·4	2·14	8·3	DOMESTIC CONSUMERS SUPPLIED THROUGH PREPAYMENT METERS AND TAKING A SUPPLY FOR LIGHTING ONLY (*I.E.E. Journal*, 1932, vol. 71, p. 879, Table 5)
3	—	78	0·689	15·57	1·46	4·5	2·24	6·9	
5	—	92	0·729	15·93	1·52	3·9	2·31	6·0	
7	—	108	0·776	16·35	1·58	3·5	2·40	5·3	
and over	—	115	0·829	16·53	1·65	3·4	2·47	5·2	
3	150	80	1·015	13·75	1·7	5·1	2·4	7·1	RESIDENTIAL CONSUMERS TAKING SUPPLY FOR LIGHTING ONLY, WITH A PROPORTION USING IRONS THROUGH THE SAME METER (*I.E.E. Journal*, 1932, vol. 71, p. 879, Table 4)
5	400	130	1·146	14·83	1·88	3·5	2·62	4·8	
7	700	220	1·361	16·72	2·19	2·4	3·03	3·2	
9	1 050	350	1·688	19·42	2·65	1·8	3·62	2·5	
11	1 400	490	1·969	21·54	3·04	1·5	4·11	2·0	
13	1 800	630	2·413	25·63	3·69	1·4	4·97	1·9	
15	2 200	775	2·807	29·05	4·25	1·3	5·70	1·8	
—	100	80	1·331	19·2	2·29	6·9	3·25	9·8	SHOP LIGHTING (*I.E.E. Journal*, 1932, vol. 71, p. 880, Table 9)
—	300	215	2·241	29·8	3·74	4·2	5·54	6·2	
—	500	315	3·130	40·0	5·13	3·9	7·13	5·4	
—	700	400	4·000	50·4	6·50	3·9	9·00	5·4	
—	900	475	4·900	60·8	8·00	4·0	11·00	5·5	
—	1 000	510	5·320	63·0	8·47	4·0	11·60	5·4	

* These values are derived by using the formulae for costing given by Messrs. Woodward and Carne.
The reader should refer to Messrs. Woodward and Carne's paper in order to obtain more detailed characteristics of the consumers considered above.

on capital, i.e. the excess of revenue from working, over working expenses when expressed as a percentage on the total capital expenditure. Table 18 demonstrates the nature of the component costs involved in providing supply to the domestic consumer with a low annual consumption. In the case of the consumer with a 4-roomed house and an annual consumption of 100 units it will be seen that 30 per cent of the annual revenue is required to meet the " consumer cost " (at 10 per cent profit), and a further 59 per cent to meet the charges on capital, leaving only 8 per cent in respect of maximum-demand charges and 3 per cent as the working cost of units. It will also be noted that a flat rate of charge below approximately 6d. per unit would cause the consumer whose annual consumption is 100 units and less to be unremunerative, even for the larger class of undertaking to which the costs refer in the formulae.

When considering the wider range of domestic consumers, it will be observed from cols. 4 to 8 of Table 18 that a two-part tariff, in which the fixed annual charge to the consumer is based upon number of rooms, floor area, or connected load, is not equitable.

DISCUSSION BEFORE THE INSTITUTION, 11TH MARCH, 1937

Mr. J. W. Beauchamp: The author refers to the falling average of supplies for domestic purposes due to the connection of large numbers of small users; we know that the consumption of electricity in the home is going up by leaps and bounds, and while the average per connection has fallen as a result of many small houses being connected such connections are a great asset. I only regret that in many districts those permanent connections are of small capacity and have inadequate wiring.

Some of the larger and better-developed supply undertakings which cater for the domestic load could get for us all accurate information about the effect on the total load of an undertaking arising from the installation of very large blocks of cookers; at present few can say with certainty what is the diversity or whether the load factor of a large city undertaking would be increased by adding, say, 50 000 cookers; that information can be obtained by taking network readings and adjusting against a careful scrutiny of consumers' apparatus and practice. The author says that we ought to reduce tariffs in advance of the business to be secured, but for many this must appear a counsel of perfection when one considers the vast amount of capital to be raised in order that it may be sunk in distribution networks.

The present multi-part tariffs work well for consumers with incomes above a certain level, but for the great mass with low purchasing power we need simpler tariffs carrying with them the apparatus through which the electricity is to be used. In short, the time has come for the supply industry to invest millions of money on the consumer's side of the meter.

I disagree with the author's suggestion that we should maintain such power loads as we have at low prices, but not necessarily extend them; a great power load is the best foundation upon which to build up the general electrification of the country; the author seems to fear that in selling power at low rates we may be subsidizing industry; that would not necessarily be an economic crime, and the prosperity we brought to the producer of goods might return to us through the increased prosperity of the wage-earner and consumer of goods.

Mr. J. W. J. Townley: I have examined the paper carefully to find a reason for the author's pessimism with regard to domestic electricity supply. On page 434 he states " the domestic load continues to be restricted, the fixed charges per unit sold remain high, and a condition of expanding demand with consequent falling costs becomes impossible of achievement." My impression is that he has cast his net rather too widely in attempting to view this matter from a national standpoint. If instead of national statistics he had given figures for a group of progressive undertakings which are developing domestic supply, he would not have arrived at such a pessimistic conclusion. The addition of large numbers of small consumers must clearly be a factor contributing to the reduction of the consumption per consumer.

I should like to give the figures for my own undertaking (West Ham) but which apply to any industrial area, because 70 per cent of consumers in this country are small working-class consumers. In 1926 we had 2 720 domestic consumers, and the average consumption was 319 units. In 1934 (after the commencement of an intensive development scheme the object of which was to attract new consumers) the number of consumers had risen to 31 471, with a reduction in the average consumption per consumer to 286 units. The number of domestic consumers is now (1937) 46 650, and the consumption 456 units per consumer—a much larger figure than we have ever had before.

In my opinion increase in the consumption of domestic consumers will not follow automatically on a reduction in tariff. What has to be effected is, coincident with the reduction in tariffs to a reasonable figure for the area, the introduction of a sales scheme for putting into the possession of the consumer high-current consuming devices such as electric cookers, water heaters, and wash boilers. An examination of the figures of such undertakings as those of Hull, Norwich, Nottingham, and West Ham shows the effect of such a policy. It is strange to hear the author say that the prices for domestic supply are too high, in view of the inclusion in his paper of the data prepared by the E.D.A. to show at what price domestic supplies can be given in this country. Those figures were prepared a few years ago, and the proportions are considerably altered to-day, but they show that 70 per cent of the ultimate consumers in this country can obtain domestic supply at a running charge of ¾d. or less, and that 30 per cent can obtain it at ½d. or less. This suggests that domestic-supply prices are not too high, because development is possible even on a running charge of ¾d. per unit.

There is another factor which enters into the question, and that is that the principal piece of apparatus to increase domestic consumption—the electric cooker—is increasing in numbers at the rate of over 30 per cent per annum. In my own undertaking, 4 years ago we had 800 electric cookers out; to-day we have 10 800. There has thus been an increase of 10 000 cookers in 4 years among a population of under 300 000 people.

Table 2 is the basis on which many of the authors' conclusions have been formed; I find it very difficult to discover what this table really means. Hitherto the Electricity Commissioners' Returns, on which this Table is based, have not differentiated between purely domestic supply and lighting, heating, and cooking, including supplies for lighting and heating to commercial premises and shops. If the figures in Table 2 do in fact include supplies to shops and commercial premises, they may be misleading.

Reference is made in the paper to the factor " units sold per £ of distribution capital "; my own figures for this are 113 for 1925, 68 for 1932, 85 for 1936, and 90 for 1937. These values indicate that unless all the facts are known it is misleading to attach any importance to this factor.

I agree with the author that we have far too many steps in our standing charge. He aims at having one fixed amount—say £6 a year—for every domestic consumer no matter of what size the house may be. This is an ideal, but I do not think it will be attained.

I believe that co-ordination will result in considerable advantages if it brings about some uniformity in tariffs, but we cannot have strictly uniform tariffs because different parts of the country have different needs and different psychological reactions to particular tariffs. It cannot be too often and too publicly stated that amalgamations will not reduce the cost of supply to the consumer in the large centres of population, and indeed amalgamation may delay the effect of further reductions in charges in such areas.

Mr. H. M. Sayers: The author has found that, taking the whole country, the charge which will satisfy all costs of the supply for domestic consumers is £3 per annum per consumer, plus ½d. per unit. The rational basis for the price of any commodity or service should be the cost, and if the costs are different for different classes of consumers the prices charged should also bear some relation to those differences in cost. The author's own figures show that a number of undertakings cannot at present supply domestic consumers on the tariff quoted above. The dividing line between undertakings which can do that and those which cannot is not very far from 10 million units sold per annum, which the McGowan Committee suggested as the boundary separating the inherently efficient and the less efficient undertakings. It is certain that a considerable number of consumers, especially those in rural districts and outlying districts of great towns, where there may be 4 consumers to a mile of main, cannot be supplied at the rate of £3 per annum for standing charges. Presumably the consumers whose proper share of charges is less than £3 are the densely grouped consumers. If one charges such consumers more than their proper share and other consumers less than their proper share, one is encouraging the less remunerative class of consumption and discouraging the more remunerative class. That, the author says, is what we have actually been doing as between power and domestic consumption, and he wants to stop it.

Messrs. Woodward and Carne have shown a way* of finding out what it costs to supply each class of consumer, and their method should be adopted immediately and carried as far as it can be. I think that flat-rate tariffs so determined will be more attractive to many consumers than any kind of two-part tariff, which seems to make a charge for nothing at all.

The author divides consumers into two classes—power and domestic. There are, however, large classes, e.g. shops, hotels, cinemas, and theatres, that do not fit into either of those categories. These call for a particular kind of tariff, which might be perhaps of the classified flat-rate type.

Mr. Beauchamp has just said that it is not very good policy to discourage the power consumer. If I understand the paper aright, the figure of £3 per annum per domestic consumer has been obtained by charging back to the power consumer a good deal of what the author thinks he is undercharged. I imagine that if anyone tried to do that there would be a considerable loss of revenue, and I do not suppose anyone imagines that such a procedure is generally practicable.

Finally, while a uniform flat-rate tariff throughout the country might be a very good thing, the machinery by which that uniformity is to be imposed must closely approximate to nationalization; which may, or may not, be desirable.

Mr. D. J. Bolton: A tariff is governed by supply (based on costs) and demand (based on utilities). The author's thesis is that the present ratio of 3 : 1 in the mean prices for domestic and industrial supplies is not justified by the difference in cost nor necessitated by the difference in utility.

On the score of costs I have two points to make. The first is that the author seems more than a little unfair to the industrial consumers. He allocates distribution fixed costs (Table 13) between industrial and domestic in the ratio of their respective units, as though the cost per unit were the same for each. Surely this is to beg the question: no wonder he arrives at an annual charge of £25 a head! Regarding domestic costs there seems a belief that an increase in consumers *per se* will lower the fixed costs proportionally. Does the diversity from consumers of the same kind increase after the first hundred or so connections? Table 13 *et seq.* implies that all past distribution costs are a direct function of the number of consumers and can be allocated at so much a head, yet all future expenses are independent of consumers and merely provide the costs total with a new and bigger denominator. If a *per capita* charge is correct for all existing expenses, how can the future ones be so different?

Regarding the demand aspect, the author seems in doubt as to the legitimacy of considering this at all. Surely it is just as rational to base a tariff on what electricity is worth as on what it costs. The plain fact is that electricity may be worth 4d. a unit for lighting and cleaning, and only ¾d. or ½d. for cooking and heating. In the domestic sphere there are two distinct groups of consumptions, which may be called the " necessity " (or high yield) group, and the " luxury " (or low yield) group. Our job is to charge as much as we can for the one so as to be able to charge as little as we must for the other. The magnitude of the first group (per consumer) is roughly dependent on " his house or his physical possessions " (page 450), and this goes far to justify much that the author objects to in present-day tariffs. Again, comparing industrial and domestic, he suggests that the present differentiation cannot be justified. Possibly the differences in size cannot, but the differences in kind certainly can, if demand is given its full weight. The most popular industrial tariff is the block-rate one, in which the low rate for big consumptions corresponds not to costs but to the competing power of the big manufacturer. The most popular domestic tariff is the "all-in" one, in which the fixed charge corresponds to the utility of the "necessity" consumption.

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* *Journal I.E.E.*, 1932, vol. 71, p. 852.

Even the difference in size of tariff, as between industrial and domestic, is exaggerated by the author's method of presentation. In the first place, 13 out of the 19 groups of Table 2 only account for about 10 per cent of the units sold; and, although the proportion of domestic units would be greater, this still gives a lopsided view of the field. More serious than this is the author's insistence on comparing mean prices per unit, whereas it is the incremental price of the extra unit that determines whether this unit shall be consumed or not. Whether the lighting price is 1d. or 1s., whether the fixed charge is 10s. or £10, may determine whether or not the consumer takes a supply or comes on to that tariff; but, once on, his subsequent consumption will depend purely on the incremental or follow-on rate. Taking all undertakings selling 10 million units or over (constituting about 90 per cent of the field), it will be found that almost every one of them offers either an "all-in" or a sliding-scale tariff, and the average follow-on or final rate of them all in January, 1936, was 0·606d. per kWh. Taking a similar survey of industrial tariffs at the same period, the average running charge of the two-part maximum-demand tariffs was 0·507d., and the average price of the last block of the sliding-scale tariffs was 0·9d. Thus the effective prices are very different from the author's figures, and in fact approximate very closely to what he says they should be (on demand grounds), as shown in Figs. 3 and 4.

Mr. H. Hooper: The author mentions the supposed disadvantage of the power load, but, as Mr. Beauchamp pointed out, it is not suggested that the power load should be done away with. Electricity to-day has to be sold in competition with other products, and competition in the power-load field is becoming more and more fierce.

The author does not distinguish between the various kinds of domestic loads. The average municipally-owned house in a big city is not paying for itself, but the average ordinary householder with a reasonable tariff in the same city is paying for himself. So far from the power load subsidizing the domestic load, some sorts of domestic loads are subsidizing others.

There is also a factor which will upset a good many of the author's calculations in the future, and that is the development of the selling of low-price off-peak units.

Mr. J. I. Bernard: The author's practice of referring to electricity as a commodity is hardly to be commended. In my view "commodity" is quite the wrong term to use; electricity supply is a service and should be referred to as such.

The elasticity of the domestic demand is dependent upon a good many other factors than those to which the author refers, namely, average prices and the average cost of competitive methods. Mr. Beauchamp has already referred to the probability that for small users it will be essential in future to provide the apparatus as well as the energy, and the elasticity of demand must also be affected by such considerations as the existence of a gas supply or the facilities which are offered for the use of gas appliances.

The author is rather pessimistic about domestic development in this country. Anyone who has studied the position must agree that in this respect we are well advanced compared with other countries. The consumption per head in this country may not be as high as in some towns in Canada where there is hydro-electric power and no gas supply, and possibly there are some other exceptions, but broadly speaking domestic electrical development is more advanced in this country than it is in any other country in the world.

The author in his opening remarks said he thought the public considered electricity to be too expensive. It is difficult to form an estimate of public opinion in general, but one method by which I have had an opportunity of doing so has been in connection with exhibitions attended by people from all parts of the country. Up to 3 or 4 years ago there was a general impression that electricity for domestic purposes was expensive, but during the last 4 years complaints from the public about high cost have entirely disappeared. The only complaints one comes across nowadays are those of lack of facilities for the installation of electrical appliances.

The author referred to electrical refrigerators and mentioned the price of £40. This was the price prevailing some years ago; to-day very good electrical refrigerators can be obtained at much lower prices, and the demand for them is rapidly increasing.

Mr. C. T. Melling: The charge made for supplying electricity is remunerative when it is greater than the incremental costs incurred, provided that the acceptance of load at such a charge does not involve a reduction in charges for existing loads. When considered on this basis, power loads, which the author considers unremunerative, are, in fact, to be desired; and although they may contribute less per unit than the domestic load towards non-incremental costs, they are assisting the reduction of domestic charges by their contribution towards overhead expenses.

Power tariffs which are based on "pooled costs" may be strictly equitable but are not necessarily economically sound, as a rigid adherence to such a basis would tend to lose business which on an incremental basis might be obtained with advantage to the undertaking and also to other consumers, some of whom may be paying more than the equivalent "pooled costs" tariff.

In comparing the average prices obtained for power and domestic supplies respectively, a consideration confined to kilowatt and unit cost would be unfair to the power load, as ignoring the first element of the three-part formulae which would represent the costs of supplying these loads. This factor is of considerable significance in small domestic supplies, and as the majority of domestic consumers take only small supplies a bare comparison of average charges to domestic and to power consumers is of little value. In general, power tariffs can be based on incremental costs, but it is difficult to ensure that domestic tariffs bear a true relation to costs. No doubt on the average domestic tariffs yield reasonably good results, but it frequently happens that a domestic consumer pays a unit charge on the two-part tariff which is less than the incremental cost of supply. For example, supply to domestic cookers in a rural area with a grid supply may well be represented by the following:—

Rating of cooker ..	6 kW
Incidence on system peak	0·2 kW (average)
Consumption per cooker	800 units per annum
Cost of current (including losses) ..	£3 10s. per kW (system peak) + 0·25d. per unit
Incremental capital charges	£3 per kW (system peak)
Incremental distribution and management charges (excluding maintenance)	2s. 6d. per cooker per annum

Under these conditions the incremental cost of the supply to the cooker is 0·68d. per unit.

Where the unit charge is $\frac{1}{2}$d. per unit on the domestic two-part tariff, there will be a loss on such a supply to a consumer who has already adopted the two-part tariff and whose fixed charge consequently cannot be credited to the cooker supply. Undoubtedly, $\frac{1}{2}$d. per unit in a rural area is unusual (though not without precedent), but in an urban area the incremental cost of supplying a cooker load of this nature may be approximately $\frac{1}{2}$d. per unit, a figure which leaves no margin to subsidize the low charges for hire made by many undertakings.

There is no suggestion in these remarks that many domestic tariffs should not be reduced further, as there is undoubtedly scope for very considerable development of the domestic load, which would be helped (although not created) by tariff reductions. On the other hand, the author's contention that we should "call a halt" in power development is strongly opposed. In promoting this power development, price is undoubtedly of great importance.

Mr. S. J. Patmore: I should like to ask the author whether, in drawing up his tables of distribution costs, he has included the money spent on sales and development work. In my opinion, the cost of effecting sales of equipment which are required to obtain the necessary consumption of energy are really part and parcel of the cost of distribution.

On page 440 he raises the important point of the provision of finance to enable owners of private plants to change over to a supply from an authorized undertaking. If the supply industry could obtain the benefit of more of these private-plant loads it should gain an advantage from the load-factor and diversity-factor point of view, and these loads should assist further in domestic-load development.

During the past few years it appears that the electrical industry has been losing a fair amount of business owing to transport authorities changing over from tramways to petrol or Diesel-oil transport. In my opinion, if the supply authorities in the towns where such changes have taken place had given more attention to tariffs and had worked in closer co-operation with the transport authorities, these loads would not have been lost. The present tendency to a rise in the price of petrol should bring an opportunity to the electrical industry for further considering the question of tariffs to transport authorities, and by means of co-operation it should be possible to get these authorities to adopt trolley vehicles instead of other forms of transport.

I believe the day is not far distant when by means of a process of continual simplification it will be possible for supply authorities to frame a tariff based on some form of service charge which will include the use of as much energy as a consumer is likely to require. In fact, I feel certain that if tariffs based on this principle and including all the necessary apparatus such as cookers, water heaters, etc., were offered by supply authorities there would be very much greater and more rapid development of the domestic load than has so far been achieved.

Mr. G. V. Harrap (*communicated*): Mr. Beauchamp has mentioned our inability to prophesy the effect of connecting, say, 50 000 cookers to the supply mains, and arising out of this remark I should like to give some figures of the increase in output resulting from the encouragement of the use of domestic cookers, wash boilers, and water heaters. The "Annual Statistical Review of Domestic Electrification," published by the *Electrical Times*, provides some reliable data on this subject, and these have been plotted in Figs. A, B, C, and D.

The data used are limited to returns from 254 undertakings in the case of cookers, 200 for water heaters, and 196 for wash boilers. The points plotted illustrate the position at the 31st March, 1936. Some of the returns from the undertakings give only the number of hired appliances, others give those hired and/or sold through showrooms, and yet others give the total known to be in service. By far the greater proportion of the cookers and wash boilers in use are hired or sold through the supply authorities. Water heaters are installed more freely, and the returns therefore do not represent such a large proportion of those actually in use. The undertakings considered cover some 23 372 773 inhabitants, or approximately half the population within supply areas. The total domestic load for 214 of these undertakings is 6 204 199 kW, and the units supplied amount to 1 867 161 409 per annum.

In Fig. A is shown the relation between the number of cookers and the number of domestic units sold for all the undertakings. It will be appreciated that cookers only account for a proportion of the units shown. No account can be taken of the price of energy in each of the supply areas, although this will very largely influence the results attained, as also will the hire charges enforced. A mean of the points plotted shows a straight-line relation, i.e. an undertaking with twice as many cookers sells twice as many domestic units.

The figures for water heaters (Fig. B) are less closely related than those for cookers. This may be because many consumers install their own heaters, and thereby upset the records obtained. There is no doubt that the number of water heaters installed is influenced by local conditions: hardness of water will have a deterrent effect, and an examination of the returns shows that holiday resorts have a high proportion of these appliances.

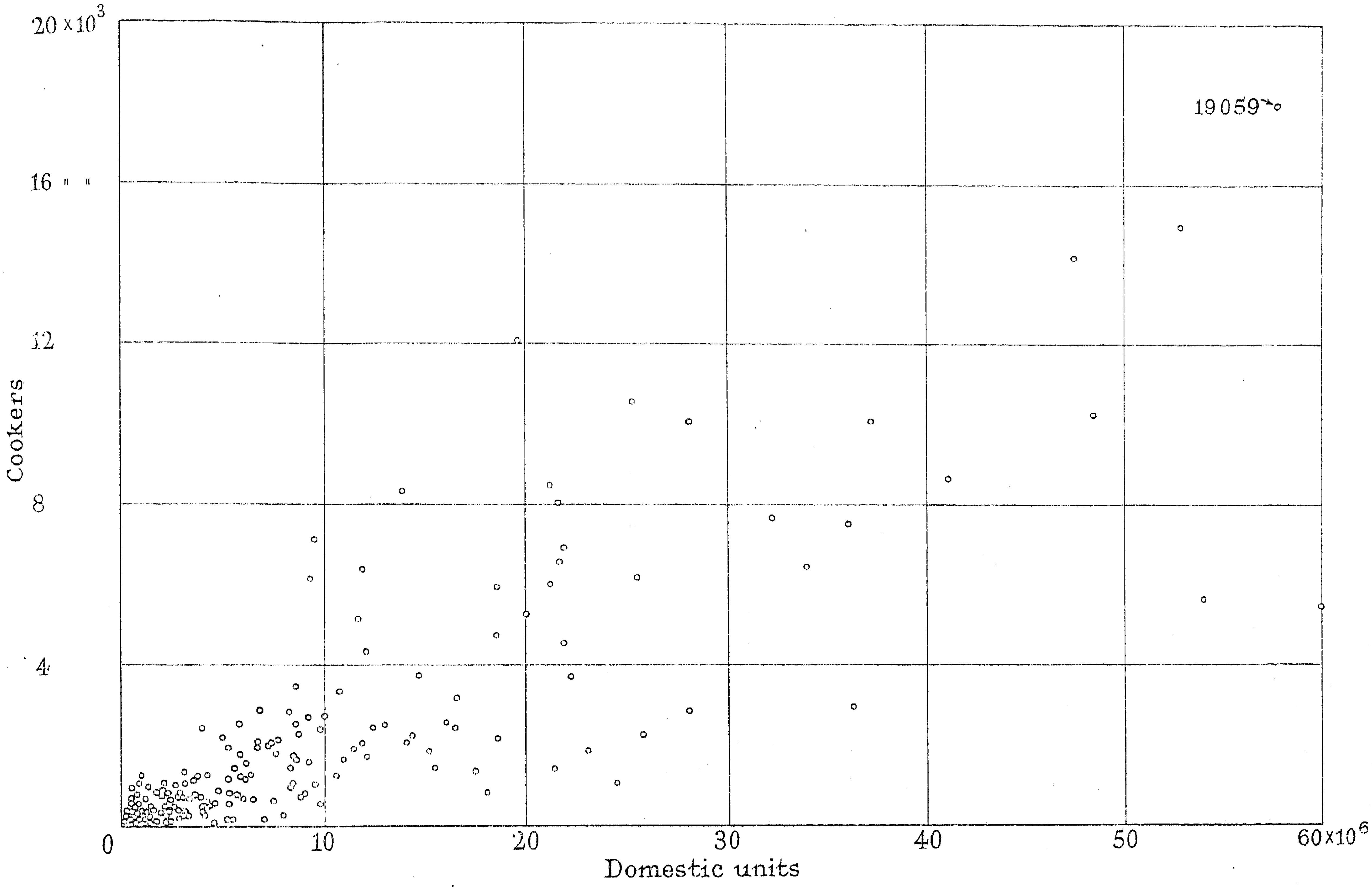
20×10³
16 " "
12
8
4
Cookers
19059
0
10
20
30
40
50
60×10⁶
Domestic units

Fig. A

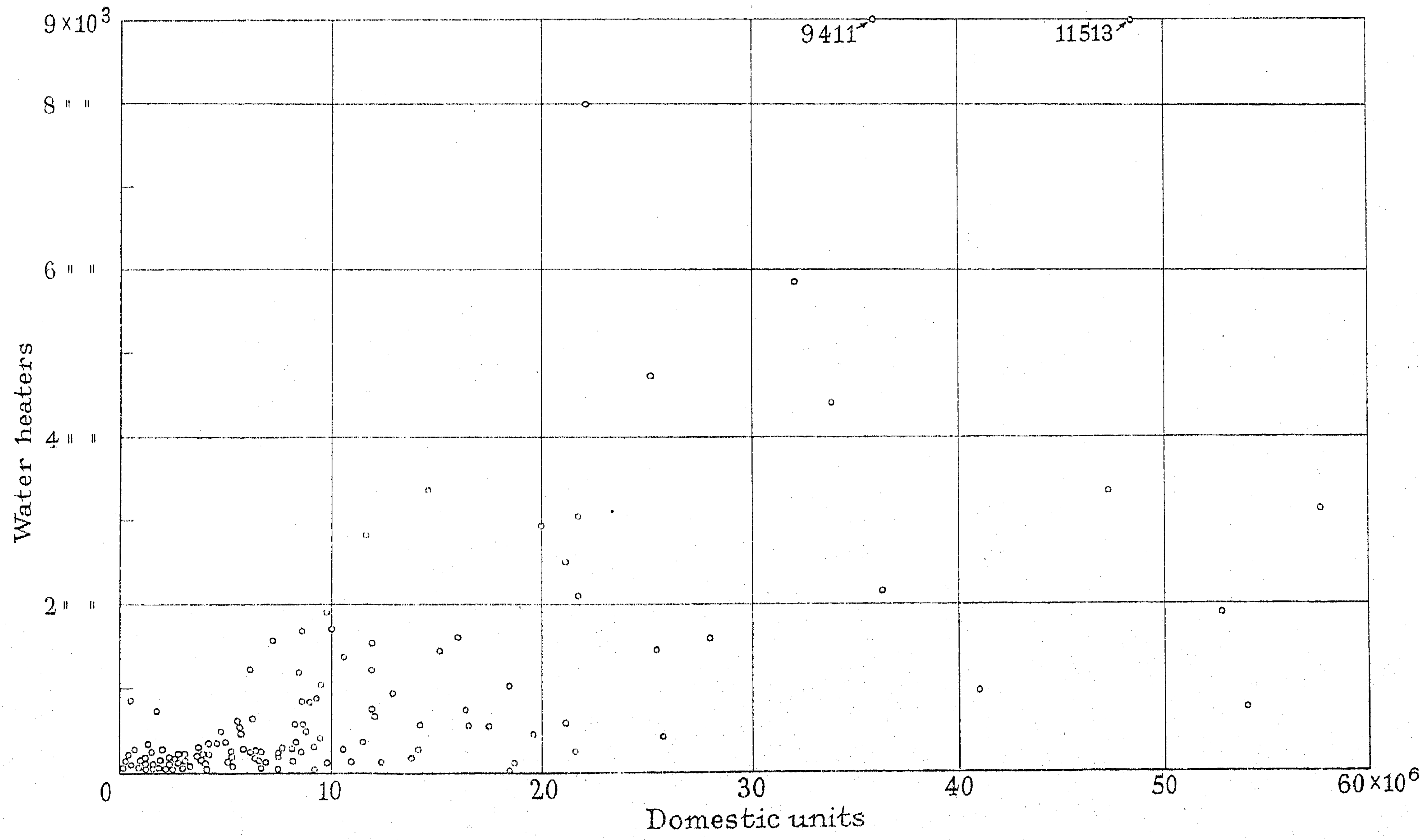
9×10³
8 " "
6 " "
4 " "
2 " "
Water heaters
9411
11513
0
10
20
30
40
50
60×10⁶
Domestic units

Fig. B

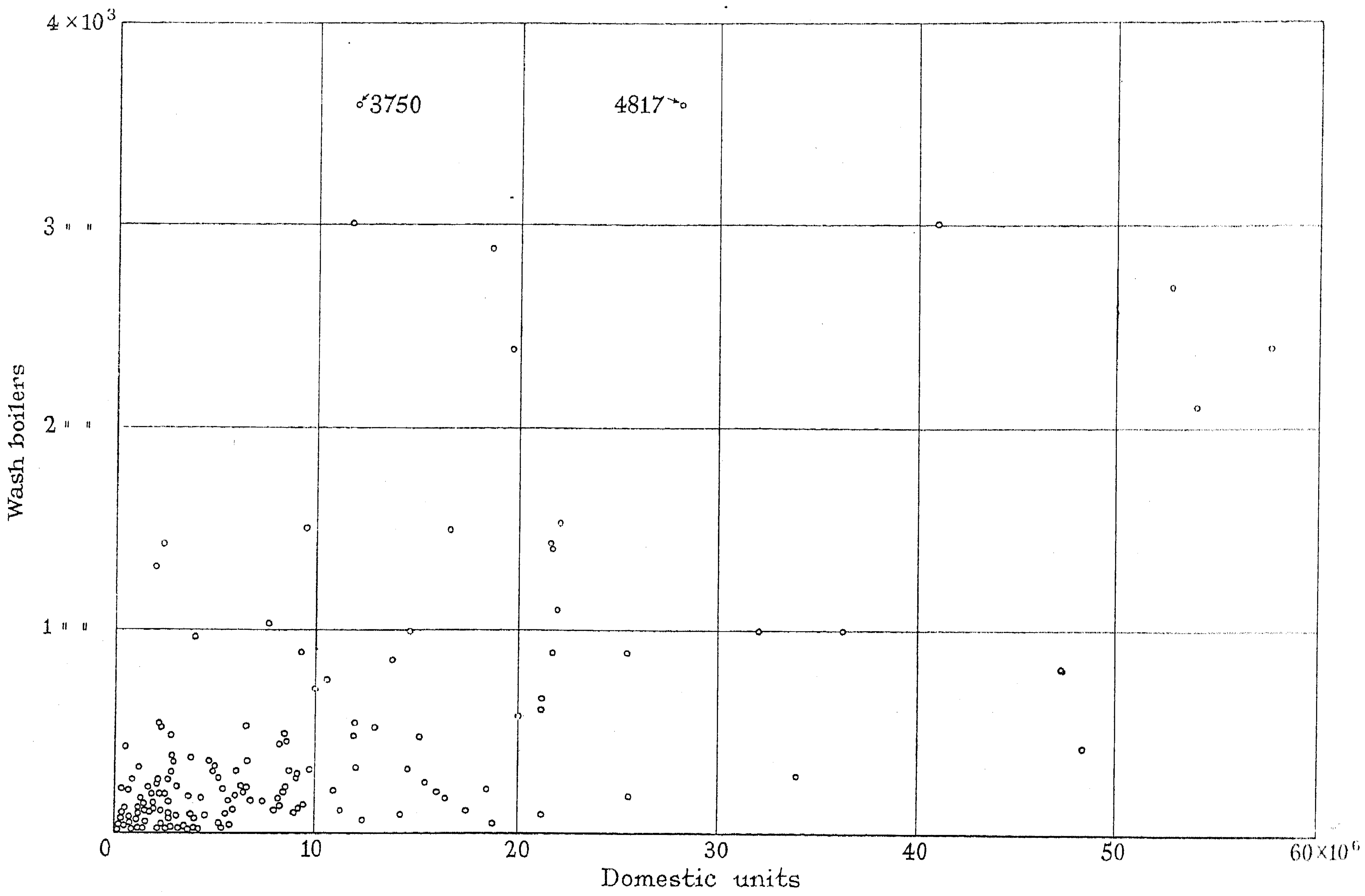

Fig. C

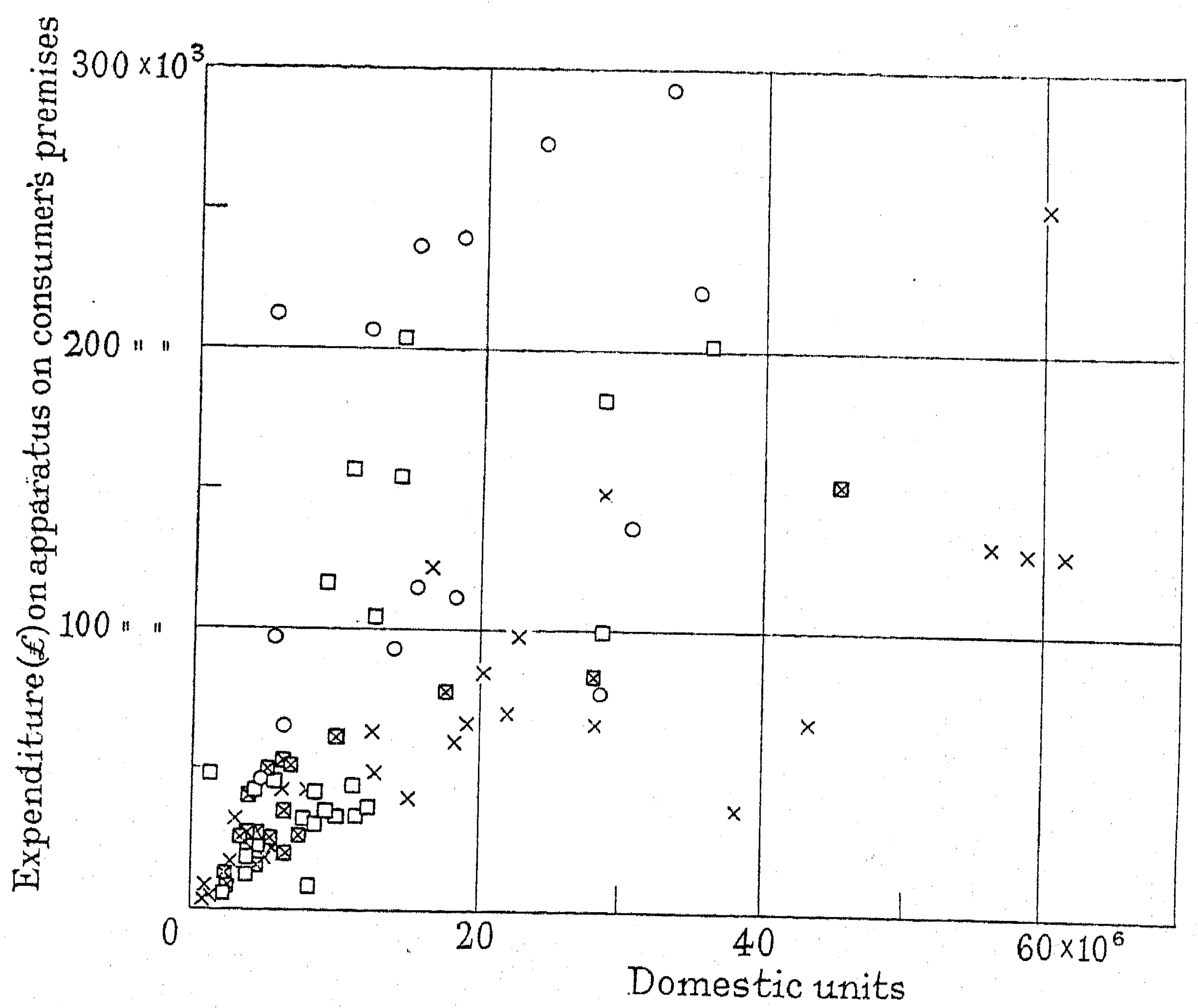

Fig. D

○ Metropolitan borough councils.
□ Extra-London local authorities.
× London companies.
⊠ Extra-London companies.

The graph for the sale or hire of wash boilers (Fig. C) is much more irregular than that for either cookers or water heaters. Water conditions and the habits of the people seem to have a large influence on the figures. Northern towns, where it is customary for the washing to be done at home, seem to obtain the better results.

Some undertakings may obtain their expansion in total units sold through the greater sale of one or other of the appliances mentioned, others by an increase in all current-consuming devices. To analyse the causes of the divergent results would be too great an undertaking, for the aggregate result of domestic electrification has so many variables and it would appear impossible to weld them into a formula depicting the effects of connecting stated numbers of cookers, boilers, or heaters.

Not only reduced unit and standing charges but also reduced hire charges and increased facilities for hire are needed to increase the domestic load. Propaganda and demonstrations are also needed, but in addition to all these is required the assumption by the undertaking of considerably increased capital commitments. This is one of the arguments for amalgamations, but before coming to a decision as to their advisability it is desirable to find whether there is a pronounced relation between this capital expenditure and output.

By confining the examination to a particular group, differentiation between types of undertakings can be obtained. In Fig. D the capital expenditure for apparatus on consumer's premises is plotted against domestic units sold. The undertakings referred to are those within the London and Home Counties Joint Electricity Authority's district, and the values given are those prevailing at the 31st March, 1936. Since the data include all capital expenditure upon consumer's premises, some will be credited to power consumers; the ratio of the number of power consumers supplied at high voltage to the number supplied at low voltage will also be important. The statistics so far published are not in a form which will allow of further breaking-down into component parts. From Fig. D it would appear that local authorities have expended more than companies. This may be due to the differences in the areas of supply and also to the inclusion of those local authorities in London which have carried out large-scale developments of the domestic load.

Further analysis of the progress of domestic electrification is very necessary. Statistics are difficult to obtain, and it is still more difficult to find a method of representation such that all the variables will assume their correct significance. The industry as a whole will look forward with interest to the publication of the information now being collected by the E.D.A.

Mr. C. W. Pass (*communicated*): In Table 1 the average domestic consumption is given as 835 units in 1931–2 and 765 units in 1934–35. Taking the estimated figures for domestic consumers from Table 14, col. 5, an approximate average consumption can be worked out for each year from 1927. This is actually 854 units for the year 1927–28, and therefore a gradual decrease is indicated in average consumption from 1927. It is clear that the value of the average consumption is not a true criterion of progress in domestic electrification. Obviously considerable development has occurred since 1927, and since a large number of low-consumption (prepayment) consumers have been connected in this period, a large increase in general consumption must have been effected in order to maintain the average at about the same level.

In Table 5 the average consumption is shown to be higher for a group of undertakings (Items 1–6) which serve for the most part good-class residential districts than for another group of undertakings (Items 7–12) which serve an industrial area. The author contends that the high average consumption in the residential area is due to the lower average price charged, but it is more likely that this is a secondary consideration and that the first reason is the widely different standards of living of the consumers in the two groups.

An average consumption for domestic purposes of 2 000 units to be achieved in 5 years is the rather optimistic aim of the author. It is unlikely that such an extensive development can take place unless the cost of domestic apparatus is considerably reduced and the consumers are able to obtain cookers, water heaters, etc., on very reasonable hire or hire-purchase terms. If we assume that the number of domestic consumers increases in the next 5 years at about the rate at which it increased in the years 1930–35, there will then be roughly 11 million domestic consumers in 1940, and with an average consumption of 2 000 units there will be a total consumption of 22 000 million units—or an increase of 17 500 million units on the total consumption for domestic purposes in 1934–35. This additional consumption must be mainly accounted for by cookers and water heaters. Assuming that the increased consumption is shared equally by cookers and water heaters and that each cooker will account for 1 000 units per annum and each water heater for 2 000 units per annum, we see that the supply industry will be faced with the formidable task of providing 8·8 million cookers and 4·4 million water heaters at a total cost of something like £132 millions.

It would appear that the high cost of electrical apparatus for domestic use is just as great a barrier to progress in building up a good domestic load as the much-discussed question of tariffs, and that it is as important to standardize the hire charges for appliances as it is to bring the tariffs into line.

Mr. R. B. Rowson (*communicated*): The basic assumption of the paper is that " electricity is a commodity the sales of which are subject to ' increasing returns ' . . ." I would suggest that this assumption is incorrect except during the first 5 or 10 years of an undertaking's life. During these years the undertaking is using up the surplus copper which was provided to cater for future requirements (or often, in the case of overhead lines, for mechanical reasons). When this stage has been passed and a distributor or network is fully loaded it is necessary to lay new copper, assuming that advantage has already been taken of automatic voltage regulation.

As the cost (C) per unit length of cable of a given voltage can be represented by an equation of the form $C = d + bA$, where d and b are constants and A is the cross-sectional area; and as the number of kilowatts (K) which can be supplied from it is also proportional to the area (neglecting inductance), i.e. $K = eA$ where e is a constant,

therefore $$C = d + \frac{K}{e}b$$

And, differentiating,

$$\frac{dC}{dK} = \frac{b}{e} = \text{constant}$$

In other words, the increment cost of conductor per kilowatt does *not* decrease.

The constant d, which is independent of the load, should be regarded as a charge per consumer, and of course decreases as more consumers are connected; but this effect is temporary and is not due to increasing demand. The cost of management per consumer also remains constant irrespective of whether the consumer uses 500 or 5 000 units per year. The only other variable is the load factor, which affects the bulk-supply price and the size of the mains necessary to give the supply. Table 4 and the top part of Table 5 show that for domestic supplies the load factor tends to remain constant at 30 per cent for large groups of consumers using more than, say, 1 000 units per annum. It follows, therefore, that the demand will increase at the same rate as the consumption.

As regards the revenue, whilst this is probably elastic from the point of view that the revenue per consumer increases as the price per unit decreases,[*] it is certainly inelastic if one considers the revenue per kilowatt of demand at the bulk-supply point or generating station. At an average of 4¾d. per unit the revenue per kilowatt of maximum demand is about £30 and falls to approximately £10 at 1d. and £5 at ½d. As there is no such fall in capital charges there is a distinct possibility that low prices and the increased use and demand which would follow would render the industry insolvent.

The most important point brought out in the paper is that electricity must be sold at not more than ½d. per unit if full use is to be made of it for domestic purposes. With this I agree, but before embarking on such a policy it is necessary to be assured that it is possible to distribute and supply electricity at this figure. The author's figures seem to show that this is not possible, for taking Item 4 in Table 4 and applying the figures given in Table 19 we get:—

	£
Annual costs	
Low voltage (2·1 × 2·5)	5·25
High voltage (3 × 1·8)	5·4
Fixed	0·77
9 500 units at 0·195d.	7·7
	£19·12
Capital	£
Low voltage (25 × 2·5)	62·5
High voltage (40 × 1·8)	72·0
Fixed	5·5
	140·0
Interest and depreciation at 8 per cent	11·2
	£30·32

This figure of £30·32 corresponds to 0·765d. per unit. At ½d. per unit the revenue would be £19·8, or in other words costs have to be reduced by 34 per cent before current can be retailed at ½d.; or, alternatively, it is necessary to have a fixed charge, in the case being considered, of approximately £10·5 per annum.

A check on the above reasoning may be obtained by considering the position of an average undertaking. Assume a bulk-supply price of £3 10s. per kW plus 0·2d. per unit with losses of 10 per cent on kilowatts and 6 per cent on units, i.e. £3·85 kW plus 0·233d. per unit after allowing for a 2s. rise in the cost of coal. At 30 per cent load factor the average cost per unit is 0·583d., or 0·533d. with a 35 per cent load factor. To the cost of bulk supply have to be added allowances for transmission, distribution, management, rates, etc., which according to Table 6 are unlikely to amount to less than 0·3d. per unit and will in all probability be more.

In view of the above it would appear that the dangers confronting the supply industry are not solely due to the admittedly unremunerative small consumer who uses between 50 and 100 units per year, but arise also from the very low domestic rates advocated in the present paper.

Table 18 is useful in showing that the author's suggestion of a uniform fixed charge is unsound. If from the revenues in col. 12 is deducted the cost of the units in col. 3 at ½d. per unit, it will be found that the appropriate fixed charge of the first consumer is £4·9 per annum or roughly double that of the remaining domestic premises referred to in the table. The fixed charge of £4·9 may also be contrasted with the fixed charge which would be necessary if full use were made of the supply (Item 4, Table 4), which, as shown above, would amount to £10·5 if the running charge was ½d.

Throughout the paper it is suggested that the smaller undertakings are inefficient, and yet in Tables 15 and 16 it is shown that in most cases the small undertakings have relatively low "consumer charges"; in fact, the highest in Table 15 is in respect of the largest undertakings, whilst the lowest in Table 16 is in respect of the 0·3–0·4 group.

[The author's reply to this discussion will be found on page 484.]

NORTH MIDLAND CENTRE, AT LEEDS, 16TH MARCH, 1937

Mr. J. N. Waite: The author has referred to the absence of appreciable increase in the efficiency of use of distribution capital and has stated that this absence of increase is contributed to by urban areas equally with rural areas. If units per domestic consumer is taken as a guide, the results of my own undertaking show a better result for the rural area than for the city area, while if return on capital expenditure is the guide the results show the city area as the better, which appears to contradict one of the author's conclusions. The area of the Hull undertaking is 160 square miles of which roughly 30 square miles are the city area, and 130 square miles outside the city boundaries. The area outside the city covers a town of 16 000 inhabitants, several small townships, villages, and hamlets, and the real rural area of farms and isolated country houses. The standing part of the domestic tariff is 15 per cent of the rateable value, and for the outside area two zones are fixed, 17½ per cent being charged in the inner zone and 20 per cent in the outer. The follow-on rate is common to the whole area, and is ½d. per unit for the first 360 units per quarter and ⅓d. for all over. The first unit rate on the Brighton system tariff is zoned, but the follow-on rates are common throughout. The small-power tariff and the flat-rate lighting tariffs are zoned, but for large power there is no differentiation.

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[*] See, however, *Electrical World*, 1934, vol. 1, p. 445, Fig. 2, p. 446, 1st col.; 1934, vol. 2, p. 778; and 1937, vol. 1, p. 1390. All these indicate the possibility of an elasticity of less than unity.

Table A

	City area	Outside area	Total
Rateable value of £15 *and under*			
Units sold	16 413 576	4 380 638	20 794 214
Units sold per consumer	376	817	424
Number of consumers	43 714	5 360	49 074
Rateable value of £16 *to* £30			
Units sold	10 407 330	4 154 240	14 561 570
Units sold per consumer	1 088	1 898	1 239
Number of consumers	9 563	2 189	11 752
Rateable value of £31 *and over*			
Units sold	3 100 653	2 657 098	5 757 751
Units sold per consumer	2 270	4 519	2 949
Number of consumers	1 366	588	1 954
All houses			
Units sold	29 921 559	11 191 976	41 113 535
Units sold per consumer	548	1 375	655
Number of consumers	54 643	8 137	62 780
All consumers			
Distribution capital	£2 031 327	£460 654	£2 491 981
Revenue return as percentage of distribution capital	27·8	22·2	26·7

To analyse the results, we divide the area into two sections: (*a*) inside the city boundary, (*b*) outside the city boundary. We then group the household properties under three headings. Table A gives the results for the last financial year, ended 31st March, 1936.

It will be seen that for a house of given size we are selling more units outside the city than inside, but the return per consumer, as a percentage of distribution capital, is less. While an unfavourable construction could be placed upon these facts, a complete analysis shows that, taken as a whole, the supply outside the city brings in sufficient revenue to cover all the costs of giving the supply: I am convinced that the policy of low price and selling a relatively large number of units yields a better financial result in all areas than does a policy of relatively high price and the consequent low number of units sold. This is particularly so in rural areas. I am also satisfied that, when a rural area is relatively close to a large centre of population, it is possible to give a plentiful supply of electricity to the rural area at a cost closely approximating to the cost in the urban centre, at no detriment to the consumers in the urban centre. From the commencement of giving outside supplies, these supplies have paid their way taken as a whole. We keep statistics showing the capital expenditure and revenue return of each individual township or village and its attendant rural area, and it is remarkable how each section has been developed to bring in sufficient revenue to cover all costs. The number showing a deficit grows less each year, and the large majority show a credit balance.

I am pleased to be able to agree with the author that a decrease in price must precede an increase in demand. It should be obvious that to create an increase in demand the price must be brought down so that it becomes attractive to the prospective user. The author appears to place great importance on a unified form of tariff throughout the country and a large reduction in the number of forms of tariff. I do not attach any real importance to this. What really matters is the cost to the consumer and, given the will to sell, the form of tariff will have no appreciable effect on the results. It is the financial result of the tariff, not its form, which matters. Undertakings with widely different forms of tariffs have achieved equally good results.

The author omits to mention one reason for lack of development in domestic consumption which, to my mind, is more important than the three reasons he does give, and that is an unduly low flat-rate lighting price. All undertakings are compelled by law to have a flat-rate lighting tariff, but all progressive undertakings have alternative tariffs with a promotional element in them, the promotional element being the fact that the greater the use the lower is the average price. The flat rate only covers the worst consumers from the author's point of view; inasmuch as their demand comes on to the peak load, they create very little diversity, and consume relatively few units. If the alternative tariffs offer no advantage to these consumers, then it is only equitable that a relatively high price should be obtained from them on the flat rate. Each class of consumer should bear the fair incidence of the cost of giving supply, and as it is indisputable that lighting units on the peak cost more than any other type of units, the charge for these should be relatively high.

I cannot agree that guarantees should be dispensed with altogether. They are still required for exceptional circumstances to avoid having to subsidize heavily particular consumers. It is my practice to cable all streets in built-up areas without guarantee, and the financial results prove that no guarantee is necessary for normal cases.

I do not think the author is justified in his general strictures about high prices for domestic supplies, nor in referring particularly to small undertakings in this connection. The McGowan Report brought out that there were 430 undertakings selling less than 10 million units per annum, and the units sold by these 430 undertakings amounted to less than 8 per cent of the total for the country; so the price at which this 8 per cent are sold cannot seriously affect the average. Hence, if any case exists, it exists primarily against the large undertakings. I would suggest the author has not kept a true sense of proportion in particularizing against the small undertakings. Many of them have had in operation the author's desideratum of a ½d. per unit follow-on rate for many years.

Table 4 does not do full justice to the load factor obtainable from domestic electrification. My own undertaking load-factor, 8 years ago, was 34·6 per cent. Since then an energetic sales campaign has been in operation, with the result that the units sold on the domestic tariff have risen from between 3 and 4 millions to nearly 38 millions; over 12 000 cookers have been connected; and over 11 000 kettles, some 3 000 wash boilers, about 1 000 water-heaters, innumerable radiators, and other incidental apparatus have been installed. The total units sold have increased by 133 per cent.

Every class of supply has increased in magnitude, but, expressed as a percentage of the total sales, all classes have decreased except domestic units, which have increased from nearly 5 per cent to 24 per cent of the total. Coincident with this increase of sales for domestic purposes, the load factor of the undertaking has advanced from 34·6 per cent to 42·75 per cent. While a number of factors have contributed to this increase in load factor, it is evident that the combined load factor of domestic supply on a large scale has a much higher value than that with which it is usually credited, and must be appreciably higher than shown in Table 4.

I cannot agree that the number of units sold per consumer is by itself a reasonably reliable criterion of progress. To arrive at the results given in Table 1, the author makes various assumptions. If his assumptions are not right, then his results will not be right. I suggest that some of his assumptions were unnecessary. He takes as the basis the total annual consumptions over a series of years for combined lighting and heating. Since 1931, all undertakings have been supplying the Electricity Commissioners with particulars of their sales and consumers, grouped under the following headings: domestic tariff, flat-rate lighting, public lighting, traction, farms, shops, offices, etc., and power. While the results for the whole country have not been published, the statistics are surely available, and there is no need to make any assumptions at all for the purpose of Table 1. I would suggest that a review of the units sold under the domestic tariff, of all undertakings, would show a very different state of affairs from that arrived at by means of Table 1.

Table B gives the results of my own undertaking over a period of 8 years, for the three classes of consumers grouped together in col. 2 of Table 1. The average consumption of the flat-rate lighting consumer has fallen from 379 to 176 units, and therefore, if the author's criterion is applied, we have gone backward instead of forward. But that is not the case. The number of consumers has increased from 13 750 to 36 432, and surely there is some merit in this. The reason for the decrease in units per consumer is that the better consumers have transferred to the alternative tariffs giving a lower average price, and also a large number of the new consumers are occupiers of small houses. It will be noted that the average consumption per consumer for the consumers under the Brighton system has fallen from 6 851 to 3 685. Again, an apparent retrogression, but the number of consumers has risen from 320 to 2 198. This increase is partly due to transfer of consumers from the flat-rate tariff, but mainly due to new consumers, and these new consumers are practically all small shops. The total units sold have increased from just over 2 millions to just over 8 millions, or nearly 4 times. Again, surely there is some merit in the increase of consumers and units. The consumption on the domestic tariff has increased from 3 650 086 to 37 840 458, and the units sold per consumer from 606 to 1 073, or nearly twice. When the averages of all the three groups are taken, the increase of units per consumer is from 550 to 708, i.e. 28·7 per cent, whereas the increase under the domestic tariff is 77 per cent. To my mind, the units sold under the domestic tariff are the only true guide to progress in domestic supply, and the total sold as well as the average per consumer needs to be taken into account.

For many years the supply industry has been extending its field, and one of the main extensions has been the introduction of electricity into the houses of poor people whose purchasing power is very limited. It is inevitable that we shall not get as good a return in units per consumer from a working-class house as from a better-class house. In my own area, of the total houses, 85 per cent are rated at less than £15 per annum, and 58 per cent at less than £10 per annum, and it is obvious that, as we extend domestic electrification, the small-size house will

Table B

ANALYSIS OF UNITS SOLD, SHOWING THE AVERAGE CONSUMPTION PER CONSUMER, FOR THE YEARS 1929–1936

Year ended 31st March	Flat-rate lighting (Houses and shops)			Brighton-system lighting (commercial premises)			Domestic tariff (houses)			Totals		
	Units sold	Number of consumers	Average consumption per consumer	Units sold	Number of consumers	Average consumption per consumer	Units sold	Number of consumers	Average consumption per consumer	Total units sold	Total number of consumers	Overall average consumption per consumer
1929	5 215 048	13 750	379	2 192 318	320	6 851	3 540 086	6 027	606	11 057 452	20 097	550
1930	6 119 832	18 012	340	2 761 223	392	7 044	4 456 515	7 987	558	13 337 570	26 391	505
1931	7 238 122	23 045	314	3 517 913	469	7 501	8 664 888	11 326	765	19 420 923	34 840	557
1932	6 786 423	25 819	263	4 428 698	709	6 246	14 630 985	16 205	903	25 846 106	42 733	605
1933	6 632 647	29 653	224	5 278 819	1 042	5 066	20 679 914	20 346	1 016	32 591 380	51 041	639
1934	6 528 531	32 845	199	6 038 548	1 371	4 404	24 490 960	24 502	1 000	37 058 039	58 718	631
1935	6 555 785	34 756	189	7 121 499	1 858	3 833	28 948 653	29 848	970	42 625 937	66 462	641
1936	6 411 620	36 432	176	8 098 914	2 198	3 685	37 840 458	35 267	1 073	52 350 992	73 897	708

increasingly dominate the figures; owing to the lower purchasing power, the number of units per consumer may tend to fall, but this will not be synonymous with lack of progress.

I gather that the author regards the price at which private power plants can produce power, and the price which domestic consumers can afford, as the deciding factors in tariffs for these classes of supply. The tariff situation, however, should be decided entirely by the costs incurred in giving the supply. Those in control of electricity supply undertakings are in the position of trustees charged with the duty of providing a service to the community at a price which bears a close relationship to the actual cost incurred. The cost of power from private plants, and the price a household consumer can afford to pay, are useful data in exploring potential markets, but they would be bad data on which to fix tariffs. Tariffs must be based on costs, taking account of the diversity of the consumer or group of consumers covered. I fail to see in the paper any justification for the statement that power is being sold at lower than cost. So far from discouraging the development of the power load, I believe we should do all we can to encourage it, for the more uses to which electricity is put the greater the resulting value of the diversity factor of use. Lighting and domestic supplies could not be given as cheaply as they are given to-day if we had no power supply and, vice versa, power could not be given as cheaply as it is given were it not for the other classes of supply. Each class of supply increases the diversity and lowers the cost of all classes of supply.

The author is of the opinion that if a uniform kind of domestic tariff with a follow-on rate of ½d. per unit were available throughout the country progress would follow automatically. With this opinion I totally disagree. The ½d. follow-on rate has been in existence in a considerable number of undertakings for many years, and yet many of those undertakings record very little progress in domestic supply. In my own undertaking, the domestic tariff with a low follow-on rate came into existence in 1924, and 6 years later less than 3 million units were being sold under it; 8 years later still, we are selling 41 millions. It is thus quite clear that a suitable tariff with the appropriate low follow-on rate will not, by itself, produce the progress desired by the author. While I recognize that a suitable tariff is essential to progress, I am quite sure that it is not so important as certain other factors.

In my opinion the most important factor in progress is that the management of an undertaking shall be firmly imbued with the will to sell. With the will to sell, the right tariff will come automatically, and so will all the other necessary factors. Let us examine some of these.

From 80 to 85 per cent of the houses in this country are working-class houses. The class of tenant inhabiting this type of house generally has no means wherewith to purchase wiring and current-consuming apparatus, and hence it is essential for the electricity undertaking to advance the capital and finance hire and hire-purchase schemes. The hire and hire-purchase schemes I have in mind are as follows: Cookers, kettles, water-heaters, and wash boilers should be available on hire, with prompt service provided free of cost. Wiring for any household purpose, either lighting or power, should be obtainable under a hire-purchase scheme covering, say, a 10-year period. Any form of current-consuming apparatus costing more than, say, £2 should be available under a hire-purchase scheme with a selection of periods for repayment from 1 to 5 years.

A competent selling staff is essential to get these schemes adopted by a large number of consumers. A necessary preliminary is that the forms and ceremonies must be reduced to the minimum. Our own motto is: "Sign on the dotted line and we will do the rest." It is important that any troubles or complaints should be attended to with great promptitude and courtesy. Our experience is that a satisfied consumer is the best sales aid.

It appears to me that a meter rent charged as a separate item in the account is certain to be a source of irritation to many consumers, and a deterrent to sales. The meter and other measuring devices are surely as much a part of the capital required to give the supply as is the distribution network, and therefore the cost of the meter should be included in the tariff and not charged for separately.

Mr. J. P. Crowther: The paper is really a plea for a more active development of electric supply for domestic purposes. The principal themes are that, owing to unattractive tariffs, large numbers of domestic consumers have low consumptions and there is a consequent danger of retrogression; and that, although many electrical engineers take an unprogressive view regarding domestic supplies, some of them are so misguided as to be selling electricity for power purposes at an unremunerative figure.

Two startling suggestions are made: (i) That a running charge of 0·5d. per unit should eventually be applied uniformly to domestic and power consumers throughout the country and that the balance of revenue required should be obtained by applying uniform fixed annual charges; a charge of £8 is suggested for power and £3 for domestic consumers. (ii) That some central authority should be empowered to operate a form of "equalization fund" which would guarantee the losses incurred by one set of undertakings, presumably at the expense of the more progressive and better-managed ones.

This seems to be anticipating the effect of the proposals contained in the McGowan Report, which points out the advantages of comprehensive areas and the resulting greater diversity of load and recommends the absorption of the smaller and less efficient undertakings into the larger. If out of reorganization we get large areas each having similar balance as between the "fat" and the "lean," then, given uniformly good management, there should be little difference in the scales of charges offered in all areas.

Table C

	Town		Country	
(1) Number of consumers	300		150	
(2) Fixed annual cost of distribution	£600		£600	
(3) Fixed annual cost per consumer	£2		£4	
Fixed annual cost (pence) per unit sold—				
(4) 3 600 units per consumer	0·13		0·27	
(5) 12 000 units per consumer	0·04		0·08	
(6) Costs of h.v. supply at town substation (say)	100s. per kVA + 0·2d. per unit			
(7) Do., allowing for losses to consumers' terminals	105s. per kVA + 0·23d. per unit			
(8) As (7), but at country substation			210s. per kVA + 0·29d. per unit	
Average cost (pence) per unit:—				
(9) For h.v. power at town substations [from (6)]	0·66*	0·34†		
(10) For town domestic supplies [from (7)]	0·71*	0·37†		
(11) For country domestic supplies [from (8)]			1·25*	0·58†

* Load factor × power factor × diversity factor = 30 per cent.
† Load factor × power factor × diversity factor = 100 per cent.

Consider distribution mains of similar capacity laid at two cross-roads, one in a town and the other in the country, with a substation at the junction, and having each of the four "legs" $\frac{1}{4}$ mile in length for the town mains and $\frac{1}{2}$ mile for the country. The 1 mile of town main is assumed to supply 300 consumers, whilst in the country owing to cheaper land and more open development the 2 miles of main can only serve 150 consumers. For the purpose of this example, the size of main selected is 0·1 sq. in. and the maximum distributed load permissible might be 400 kVA (i.e. 100 kVA per leg) in the town, and 200 kVA (50 kVA per leg) in the country. This allows $1\frac{1}{3}$ kVA per consumer in town and country alike. The fixed annual costs of distribution include repairs and maintenance, management, meter reading, and accountancy and other services; plus capital charges on the substation and, in the town, 1 mile of main and 300 connections and, in the country, 2 miles of main and 150 longer connections. £600 per annum will be found to be a reasonable total cost in both cases; and this represents £2 per consumer in the town and £4 in the country, as shown in Table C. It is interesting to note from Table C how small the distribution costs can become if the supply is used abundantly. Thus 3 600 units produce a cost of 0·13d. per unit for town and 0·27d. for country [item (4)], and 12 000 units produce 0·04d. and 0·08d. respectively [item (5)]. Energy costs must, of course, be added, and for these 100s. per kVA and 0·2d. per unit are taken as the costs of high-voltage electricity delivered to town substations, although I am aware that lower figures are obtainable in heavy industrial areas. The average costs per unit resulting from these figures at group system load factors of 30 per cent and 100 per cent are 0·66d. and 0·34d. respectively [item (9)]. "Group system load factor" is intended here to have the same meaning as in col. 5 of Table 4, allowing also for power factor. Allowing 5 per cent for demand losses and 15 per cent for unit losses up to the domestic consumers' terminals, the 30 per cent cost per unit becomes 0·71d. and the 100 per cent cost 0·37d. [item (10)].

My belief is that an overwhelming preponderance of the units sold for power are delivered direct at high voltage without incurring any low-voltage distribution costs, and indeed that quite frequently substations provided for this purpose by power consumers form free distribution centres for feeding low-voltage networks.

With regard to the proposal (made on page 454) to apply universally the same uniform running charge of 0·5d. per unit, we have only to consider that immense numbers of high-load-factor units are being remuneratively supplied to many of our great industrial works at well under 0·5d. per unit and that an increase of 0·1d. on a 24-million-units supply means increasing the bill by £10 000, to realize the shattering effect of such a proposal. If the basic costs at a town substation are £5 and 0·2d., we can deliver to the substation a 30 per cent load factor high-voltage supply at a cost of 0·66d. per unit, or, allowing for losses to the domestic consumers' terminals, 0·71d. [items (9) and (10)]. This means that for a town power consumer taking a 30 per cent load factor high-voltage supply the total costs are 0·66d. per unit, whilst for town domestic consumers with a group system load factor of 30 per cent the costs are £2 per annum per consumer [item (3)] plus 0·71d. The comparable figures in the country, which are so much higher because of the much greater distances between consumers, are 1·16d. and £4 plus 1·25d. [items (3) and (11)]. There is no evidence here that domestic supplies can be afforded more cheaply than power, or that there is uniformity of cost in town and country.

In this latter connection, it is stated on page 445 that capital expenditure in rural areas is probably as remunerative as in urban areas, although the average price is higher and the consumption lower. It seems to me that, however intensively we develop domestic supplies, this condition of higher costs must continue in the rural areas so long as the buildings are so scattered that twice the length of main is required to serve a given number of consumers. I have not overlooked the use of overhead lines, but these would not be utilized extensively if annual consumptions of the order of 3 000 units per consumer were expected.

It is interesting to note that, to justify a running charge of 0·5d. per unit at a 30 per cent load factor assuming there is to be no contribution towards the running costs from the fixed charges, the costs at the substation must not exceed 68s. per kVA and 0·15d. per unit. Consequently, there appears to be little likelihood of the converse happening, i.e. of a running charge of 0·5d. per unit making a contribution towards the fixed costs.

The author urges that the only way to save ourselves from a critical, indeed a dangerous, condition is to sell more units. But, if our fixed costs are covered by our fixed charges and we are not relying on an excess of running charge over running costs to increase the yield on capital, I see no danger in our present position and under our present system of fixing two-part tariffs.

Mr. A. Kelso: The author's figures for Harrogate are almost identical with those for Mid-Cheshire—yet Harrogate is classified as urban and the others as rural. I think the greatest percentage difference in the figures given is about 9. As far as the Harrogate undertaking is concerned, the author cannot blame us for allowing the domestic consumer to subsidize the power consumer. The figures given show that ours is the only undertaking where the average price per unit obtained for power is greater than that for the domestic supply. The author said that we should consider diversity more than load factor: to me, however, diversity and load factor are very closely associated.

As regards rural distribution, our figures for some 300 rural consumers using only a wireless set and an electric iron (in addition to lighting) show an average of 84 units per consumer per annum. I suggest that when comparing the development of rural districts with that of urban districts many factors should be taken into consideration, the chief one being the smaller spending power of the rural consumers.

A tariff with a low follow-on rate is not the only factor that is essential for improving the domestic load. My undertaking adopted the 2-part tariff as far back as 1912 but progress was very slow until about 6 years ago, when we found that what we required was, as Mr. Waite suggested, assisted wiring facilities, facilities for hiring apparatus on reasonable terms, and hire-purchase facilities. Even more than that it is necessary to educate the consumer regarding the many advantageous services to which electricity can be applied.

Mr. H. J. Fraser (*communicated*): The author suggests that power supplies are being given at unremunerative rates, thus placing a burden on domestic consumers; he also states that for many industries the cost of power averages about 3 per cent of the total cost of the finished article. This average would not hold good in the case of, say, electro-chemical works, cement works, and certain branches of engineering. These industries alone must provide employment for many thousands of workers, and to meet competition cheap power is essential. The employees are probably in their turn domestic consumers of electricity, and as their livelihood is dependent on the welfare of these industries it follows that if necessary they must pay a fairly high price per unit to benefit the particular industry which employs them.

It appears to me that the load factor of the individual domestic consumer must be considered as important as the load diversity of groups of consumers if cheaper domestic rates are to be offered. Also it is generally agreed that the units sold per £ of distribution capital are capable of a considerable increase providing the right type of load is encouraged. The type of load to be encouraged is off-peak or night water-heating load, which may generally be accepted without any reinforcement of mains, and would lead to considerable improvement in system load factor. Development in this direction has been very slow, possibly because many undertakings have regarded water heating as a daytime load, and have feared the effect of 2- or 3-kW water-heaters on the maximum demand of the system. Even to-day we find that in fully 90 per cent of new houses the main hot-water supply is provided by a coal-fired boiler fitted into the household grate. Most consumers would appreciate a tank-full of hot water with which to start the day, and would be prepared to pay a reasonable price for such a service. The average household hot-water tank may be insulated and fitted with, say, a 500-watt thermostatically-controlled water-heater for quite a modest sum. A relay under the control of the supply authority is, of course, required, but a separate meter need not be installed as the "night hot-water service" may be provided for a fixed sum per quarter. The principal problem at the moment appears to be to provide a reliable method of controlling the relays by means other than pilot wires, and probably this could be solved by superimposing high-frequency currents on the mains from the central station or from selected points on the system. Experiments have been made in this direction in the U.S.A., and it would be encouraging to learn that similar experiments are being considered in this country.

If we can only sell each of our 7 million domestic consumers a night load of 500 watts each, then the demand so created must have its effect on the valleys in the load curves of our selected stations, and the improved load factors must also be reflected in low tariffs which will be possible for this type of consumer.

[The author's reply to this discussion will be found on page 484.]

SCOTTISH CENTRE, AT EDINBURGH, 23RD MARCH, 1937

Mr. E. Seddon: In the Summary the author refers to lower average consumption per domestic consumer during a period of 8 years prior to 1935, and gives as the reason the fact that of recent years a large number of small consumers has been added whose use of electricity is restricted to lighting. I do not think it will be disputed that during the past decade or so the gradual reduction of tariffs to domestic consumers has brought in a new class of user, namely the small wage-earner, whose first thought is of electric lighting with its advantages over other illuminants. In this city during the past few years a large number of small dwellings have been wired and connected to the supply, and this has had the effect of lowering the number of units used per consumer (the present figure is 733); but the supply engineer should not be unduly disturbed at this lowering of average use, as it will only be a temporary setback. Already the tenants of small property who cannot afford to send clothes to the laundry find that such appliances as a wash boiler and an electric iron are a great boon to them, and they gradually learn from experience that the cost of these compares favourably with that of the methods previously used.

I want to support the author's statement at the end of his Summary, where he deplores the absence of a unified tariff basis. I have no doubt that the Bill following the McGowan Report will provide for the unification of tariffs in the reorganization of distribution.

In Edinburgh the average price received from domestic consumers is of the order of 1·22d. per unit; which I submit is a low average figure, but in the case of large houses of 8 to 10 rooms, consuming 10 000 units per annum, the average rate comes down to about 0·625d. per unit, at which figure electricity can be used extensively.

Regarding the general subject of tariffs, I think the telephone method of a service charge plus a rate for the use made of the service forms a model system for us to copy, with the exception that in the case of the telephone one subscriber cannot make a greater instantaneous demand than another, whereas the demands made by electrical consumers differ greatly. It seems to me that a suitable domestic tariff would be a minimum service charge for (say) a 4-room house, which would be increased in some suitable proportion to provide for larger houses with a greater demand, plus a unit rate of (say) 0·5d. for the first 10 000 units, 0·4d. for the next 10 000 units, and so on. A stepped rate of this nature offers a definite inducement to a consumer to use electricity for all his needs.

The author makes mention of the efficiency of use of distribution capital. Unfortunately the cost of securing suitable substation sites, together with the present high cost of switchgear and cables, is having an adverse effect on the efforts of most supply authorities to increase the units sold per £ of capital.

Mr. J. Gogan: I consider that much of the difficulty of undertakings having two forms of domestic tariff could be avoided by introducing one tariff with the rates in the form of steps. For the first step the rate would be the flat rate as charged by the undertaking for lighting purposes; and a quota of units per room in a house, or per 60 watts installed in business premises, would form the first step. As the second step the quota of units could be arranged at, say, 10 times the quota of units required in the first step; the revenue received from the first and second steps (at rates to be fixed) should be equal to the rental charge plus the total of the units at the first and second step sold at the running charge. For the third step all the units in excess of the first two steps could be sold at the running charge already existing under the rental system or two-part tariff.

This arrangement gives one tariff for all domestic or small business-premises consumers. It avoids the necessity for changing consumers from flat rates to renta two-part tariffs. It cuts out the anomalies that arise under the rental system of taking a percentage of the valuation basis, more especially in company undertakings where the valuations may change between one district and another. This arrangement of tariffs is operating in at least three undertakings, and could be conveniently used as a universal form of tariff throughout the country.

In his verbal summary of the paper the author gave examples which indicated that the public are not satisfied with the electricity supply and service. I disagree with this, and in support of my disagreement I would mention that the Consumers' Protection Association which was set up some time ago did not get much support and has ceased to exist. One can only draw one conclusion from this, namely that the public are satisfied.

I do not agree with the method of subsidizing one consumer to the disadvantage of another from the revenue obtained from the rates. Systems of costing should be so arranged that each consumer pays his proper proportion for the service obtained.

The author implies that the power load is subsidized by the domestic load, but I do not think that this is the case. In the undertaking with which I am associated the general load factor is 40 per cent, and the load factor of the domestic load is 25 per cent. Therefore the power load-factor must be very much higher than 40 per cent and naturally the rates quoted should be lower for the supply having the more favourable load factor.

In Fig. 5 the units sold per £ of capital expenditure are shown as falling sharply in 1926; I consider that the dip in the curve is due to the depression following on the coal strike and the increased costs of coal to the undertaking, not to any defect in the charges for electrical supply.

Dealing with the general development of the domestic load, care should be taken to encourage consumers to connect apparatus that will give the highest annual revenue per kilowatt of maximum demand.

Mr. Alexander P. Robertson: After reading the paper I came to the conclusion that the author divides the tariff question into two parts, industrial and domestic. I gathered that he is in favour of getting as much revenue as he can for the industrial load, by quoting a little below the price at which electricity can be supplied from a private plant. Perhaps that may be good practice, but I do not agree with it. The domestic load is in quite a different category: I think that in regard to the domestic load the psychological aspect looms very large. If there is an initial charge and once that charge has been paid all the units are supplied at a cheap rate, then people do not worry about how much electricity they are using. Now the usual charge for electricity is below 1d. per unit, and a person paying that price per unit for all purposes does consider it dear.

Some years ago I made some tests and found that if the unit charge was less than ½d. heating by electric radiators compares very favourably with heating by coal fires. Coal may cost 2s. per cwt., or roughly 5 lb. for 1d. A good fire which will heat a room of reasonable size requires 2½ lb. of coal per hour, which costs about ½d. A radiator consuming 1–1¼ units per hour will give the equivalent of this amount of heat, and if electricity is supplied at ¼d. per unit—and that price can be attained quite near to here—electric heating is the cheaper.

There are many different ways of arriving at the constant charge of a two-part tariff. In the industrial tariff the maximum-demand charge causes a lot of controversy with consumers. One drawback is that if they have a busy time, lasting even for only a week, they have to pay for 3 months or a year at the high maximum-demand rate. The consumers forget the low average cost per unit because the maximum-demand charge looks very large.

Turning to the question of application forms, I do not think that these are beyond the comprehension of the majority of people who have to sign them.

Mr. Gogan suggested block rates; these are desirable in many ways, but it is very difficult to make the blocks small enough for the small consumer.

Mr. J. Eccles: The author cites a number of reasons why distribution efficiency expressed in units sold per £ of distribution capital has not improved over the past 10 years, but he omits some of the most potent factors contributing to this condition. Until the passing of the Electricity (Supply) Act, 1926, the division of capital expenditure into generation and distribution accounts was not of actuarial importance to most undertakings, and hence the allocations were made on common-sense rather than on highly scientific principles. To take but one example, the cost of everything inside the power station was then regarded as being defrayed from generation capital, whereas under present methods the costs of practically the whole of the main switchgear and the portion of the power-station building containing it are debited to distribution. The hiatus in the efficiency figures in Table 8, col. 5, at the year 1926–27 is most probably due to this new method of accountancy, for although the C.E.B. did not commence commercial operation until some years later most large undertakings commenced to revise their capital allocations about this time. Confirmation of this view is shown in Fig. 6, where for the year 1926–27 the percentage distribution capital rises sharply, with a corresponding diminution in the percentage attributable to generation. One of the consequences of the 1926 Act is that the number of generating stations has been reduced and hence the average distance between power station and consumer has been very materially increased, which in itself entails additional distribution capital per unit sold. Further most undertakings have, as a consequence of interconnection, been compelled to spend large sums in augmenting the rupturing capacity of distribution switchgear to meet the new conditions—an expense which is in no way related to the units sold. It is thus apparent that the effect of the 1926 Act has been to load up the distribution-capital account with expenditure which is independent of sales, and as this expenditure has been spread fairly uniformly over the years since 1926 the result has been a steady repression of distribution efficiency during that period. When it is also remembered that the annual cost of change of frequency (including that incurred on generating plant) is debited to distribution, and that income tax, which formerly was shared between generation and distribution accounts, is now chargeable solely to the latter, the marvel is not that distribution charges per unit sold are stationary but that they have not considerably increased. During the period under review most undertakers have been engaged in the unremunerative business of changing over from d.c. to a.c. distribution and, so far as this expense has been defrayed from capital, it has prejudiced the position still further.

The first half of the past decade was a period of internal changes in which most of the readjustments favoured generation at the expense of distribution, and it would be unwise to apply general conclusions deduced therefrom to times of normal progress and development. Table D, which has been calculated from the author's Table 8, shows the relative capital expenditures during the past 10 years.

Table D

Year	Annual capital expenditure on generation	Annual capital expenditure on distribution
	£ millions	£ millions
1924–25	7·5	11·7
1925–26	7·5	14·2
1926–27	4·8	16·5
1927–28	12·2	16·8
1928–29	11·7	16·2
1929–30	8·1	19·2
1930–31	6·6	18·0
1931–32	5·0	17·9
1932–33	4·5	18·1
1933–34	1·7	17·3
1934–35	1·0	19·0

That the rate of expenditure on distribution has been practically static since 1929–30 would appear to indicate an approach to more stable conditions. On the other hand, the rate of expenditure on generation has diminished to practically zero in 1934–35, an achievement which cannot long be maintained. It would therefore seem to be safe to predict that, if the industry does not suffer further upheavals, the next few years will witness a rise in distribution efficiency and a retardation of the rate of growth of generation efficiency, both expressed in units sold per £ of capital.

The author draws attention to the disparity between the prevailing average charges per unit to domestic and to power consumers, but in so doing rather prejudices the argument by suggesting that all the high-priced lighting units are paid for by the former. Power consumers may be divided into two broad classes, namely (1) two-part tariff, and (2) flat-rate consumers. For Class (1) the lighting consumption is quite frequently metered separately and an extra charge imposed for the units so metered, whilst for Class (2) the separate metering of and extra charge for lighting units is general practice. In making returns to the Electricity Commissioners the practice of undertakers varies with regard to the allocation of the high-priced units and the corresponding revenue from Class (1) power consumers, but for Class (2) consumers the high-priced units and the revenue therefrom are quite properly returned as lighting. In the author's analysis the whole of these high-priced units are assumed to have been paid for by the domestic consumer. Similarly all shop lighting has been attributed to the domestic consumer. It is difficult from the statistics available to proportion out the lighting correctly between domestic and power, but in view of the important deduction made by the author from these statistics it would have been worth while to have analysed the returns of a number of representative undertakings from this point of view.

The author suggests a form of tariff in which the standing charge is equal for all domestic consumers, but the impracticability of such a method of charge requires no emphasis. What is really required and what all the existing tariffs try, with varying degrees of success, to effect, is to extract a standing charge which is proportional to the ability of the consumer to pay. One sympathizes with the author in his quest for a simplification of the types and a reduction in the number of tariffs, but his suggestion that a statutory commission should be set up to dragoon the industry into a particular line of action cannot be accepted as either necessary or desirable. We all wish to see electricity used to the fullest possible extent, but in our endeavour to achieve this result we should maintain a balanced perspective on fundamentals. In this respect it would probably be agreed that (1) The industry has just passed through a period of evolutionary changes without parallel in its previous history, and conclusions based on experience in this period are apt to be misleading. (2) The industry must always be self-supporting, and decisions whether or not to reduce tariffs in advance of increases in consumption must in the ultimate be made by the executive officers responsible for the financial stability of their undertakings. (3) The electrical consumption in this country in 1936 had increased by 95 per cent over the consumption for 1929, which might be taken as indicating that present methods are not wholly unsatisfactory. (4) What the industry most needs is a period of freedom from external interference, legislative or otherwise, so that the true effects of past legislation may be properly assessed.

Mr. G. G. L. Preece: Dealing with the question of unrestricted supply, to which the author referred in his verbal summary of the paper, I do not believe we shall ever achieve what we ought to be doing in the industry until unrestricted supplies are universal. I believe the more risk that one takes in such matters the greater and quicker will be the development of electricity supply.

Prof. M. G. Say: Statistical arguments cannot always be completely convincing, and I do not feel convinced that the domestic consumer is subsidizing the power consumer. I do not mean that I hold the opposite view: only that the evidence seems inconclusive. For the past 15 years my electricity supply has been provided by the municipal authorities in Glasgow or Edinburgh, and it would appear, in these cases at any rate, that the domestic consumer has been subsidized by the power consumer. I have been enjoying annual consumptions of 12 000–15 000 kWh at prices below 0·6d.

Some of the figures in the paper seem peculiar. Thus in Table 4, col. 2, item 5 represents a three-roomed house with only 150 watts of installed lighting, which for a "typical" case seems extraordinarily small. Items 1 and 2 in the same table call for comment: item 1 has seven times the connected load of item 2, but practically the same consumption, and that a small one. In Table 5, items 7 to 12, the domestic consumers are somewhat arbitrarily assumed to be 90 per cent of the total. Is there a reasonable foundation for this? I do not understand the second and third columns at the foot of Table 19: should not these be interchanged?

Mr. Andrew Morris: The slow development on the domestic side in units per £ of distribution capital gives the author concern, and he refers on page 429 to the contribution of urban areas to this state of affairs. At the present time this is hardly to be wondered at. Within the past 5 years, areas which one remembers as acres of green fields have been covered with houses relatively sparsely spaced, which have involved heavy expenditure on new mains, distributors, and services. One anticipates, however, that these new consumers will increasingly appreciate the advantages of their supply, and we can therefore expect an increase in the efficiency of distribution capital expended on them.

The author's assumption that the low power rates indicate that power consumers are being subsidized by the domestic consumers is open to dispute. We have one power consumer who recently doubled his load to 2 500 kW. As this consumer is on the e.h.t. ring main, the extra distribution capital needed to meet the new load was relatively small, and a consumption of approximately 18 000 000 units per annum justifies a very low rate. A domestic consumption of this amount would cost very much more to supply. This may be a special case, but our ordinary power rate in Edinburgh is also low, the first 2 000 units being charged at 1d., the next 50 000 at 0·75d., and the rest at 0·7d.; yet our domestic heating rate at the same time is ½d. per unit, which does not indicate that domestic consumers subsidize the power consumers. Indeed, the reverse would appear to be the case in Glasgow, where, under the ordinary power rate, the first 40 000 units are charged at 1d., whereas the domestic consumer may reach ¼d. per unit for heating.

The plea to consider the matter from the national aspect also raises a query. Referring to Table 2, one gathers from cols. 2 and 3 that more than 50 per cent of all supply undertakings sell less than 3 million units per annum. Is it suggested that the consequent high price per unit should be a factor to influence the rate which larger undertakings are able to charge at present?

Still considering Table 2, I do not follow the origin of the figures in col. 10. I take it that the average revenue obtained per domestic unit sold, multiplied by the average annual consumption per domestic consumer, should give the annual income. In other words, col. 7 multiplied by col. 9 should give col. 10. On working out these figures I find that the results vary from 18 per cent less to 100 per cent more than those given by the author.

Reference is made to the use of two-part tariff meters. I should be glad of some information concerning the author's knowledge or experience of these instruments, as one hears conflicting reports of their suitability.

Mr. C. Collyns: I should first like to point out that the higher charges for electricity in rural areas are due to the capital expenditure involved in getting the supply to a consumer who lives some distance from the mains.

In connection with the author's figures in Table 2 which tend to prove that the domestic consumption per consumer is dropping, this decrease is probably due to the large number of small consumers, but I do not think we should be unduly pessimistic about it. We hope that these consumers in time will increase their consumption. We must remember that the majority of these small consumers are occupying housing schemes all over the country, both urban and rural, and that during the first 5 years of their tenure they are faced with a large number of other commitments. As a consequence such consumers have not increased their consumption.

It is probably very desirable that there should be a standard tariff just as for the telephone, but the tariff problem is a vicious circle which starts with the Central Board's standard charge. The standard charges of the Central Board are based first of all on the basic load, and then the reductions are fixed in terms of the basic increment to that load; with the result that those undertakings which started off with a good basic load when the Central Board came into being have the advantage of a cheaper rate than the smaller undertakings. The difference is very marked when one compares the prices in various parts of the country. Thus before anything else can be done the Central Board must give a lead in the direction of more suitable tariffs.

Curve B in Fig. 5 agrees very closely in shape with a similar curve I took last year. The dip in our curve occurs in 1929, however, instead of in 1926–27. For the latter year we show an increase rather than a dip, possibly owing to the depression reaching Scotland later. I should be interested to know whether there is any other explanation for this.

With regard to two-part tariff meters, the author suggests that they are a good thing, but my experience is quite the reverse. A possible explanation may be that in this part of the country the daylight in the summer time lasts very much longer than farther south; we have found that unless a cooker or some large current-consuming device is installed two-part tariff meters are not very satisfactory, because in this part of the country at any rate, and more especially in the rural districts, consumers go to bed in the daylight and so use very little electricity for lighting. Now with the two-part tariff meter the dial continues to revolve, piling up the fixed charge, and with the return of the longer evenings the consumer is faced with paying the accumulated arrears before he can get any light at all; or if he gets some light it is only a small proportion and he has to pay up the fixed charge very rapidly instead of settling throughout the year.

I agree with the other speakers who have rather deprecated the suggestion that the power charge should be increased. This view is surely the obvious one, in view of the difficulty of getting power supplies at all at the present time, more especially in rural areas where one is faced with collieries and with paper mills which generate cheaply or use steam for process work.

Mr. E. Simister: My impression is that the author intends us to take the paper from a national and not from a local or individual standpoint. Prior to the coming of the grid the bogy of peak load affected costs throughout the country. Has the grid not compensated for some of those peak-load charges which occurred in the tariffs put forward?

Whatever type of tariff we adopt, there are always anomalies. Although the two-part tariff at the present moment seems to be ideal, 20 years hence, or sooner, we shall be employing a simple flat-rate charge for electricity supply.

[The author's reply to this discussion will be found on page 484.]

SOUTH MIDLAND CENTRE, AT BIRMINGHAM, 5TH APRIL, 1937

Mr. S. T. Allen: I disagree with the basic statements upon which the author's arguments are built up. For example, in his Introduction he states "It has to be realized that a large proportion of the recently connected consumers were already on the route of existing mains and their connection has involved capital expenditure in respect of service and meter only." This is very misleading because, during the last few years, by far the largest number of new domestic consumers have been those living in new houses in new roads, generally forming part of housing estates built either under local-authority control or by private enterprise. The great majority of such new consumers have necessitated completely new distribution systems, often including high-voltage mains and static substations, as well as distributors and services. If this mistake is accepted, much of what follows the above statement must be withdrawn.

The author has taken great pains to find the reasons for what he calls the "inefficiency of the use of distribution capital." Now I disagree that the distribution capital has been generally inefficiently used during the last few years. Whereas in the past the industry has suffered considerably owing to the restriction of the amount of copper used in, and money spent on, distribution mains, etc., in recent years supply authorities have realized the wisdom of spending more money in anticipation of future developments, knowing full well that they could not expect at once an adequate return.

To use average results of the past in order to determine policies and conditions which should prevail if we are to obtain the best results in the future, is wrong and often dangerous, but this is done throughout the paper. It would have been more useful had the author given the results obtained by those undertakings which are the most efficient in the matter of domestic supply development, and analysed the reasons for the high positions they hold. If he had done this, he would have found that there are other and more important means of increasing the domestic load than those he advocates.

One of the principal methods by which the author would bring about an increase in the domestic load is a standard tariff throughout all areas, enforced through a statutory body. He recommends that the two-part tariff should only be standard as far as the secondary or unit charge is concerned, it being left to the discretion of the supply authorities to determine the amounts of the fixed charges in each case. In effect, this would mean that there would be no standard tariff. The author also suggests that supply authorities should be guaranteed against annual loss arising from the adoption of the forced standard tariff. This might result in an efficiently conducted supply undertaking being called upon to subsidize a badly managed undertaking. In fact, the compulsory standard tariff might actually, in some cases, act as a deterrent to a wholehearted development campaign.

How is it that one undertaking is able to do so much more in the matter of selling electricity than another undertaking working under similar conditions of potential load and tariffs? The answer is that for the most part the unsuccessful undertakings have not built up a sufficiently extensive organization for the purpose of selling electricity. The responsibility for the selling side is often placed upon the shoulders of the technical staff of the distribution section of the undertaking. Local influences, jealousies, and misunderstandings are sometimes responsible for this state of affairs. An undertaking which runs on its own momentum may make some progress, thanks to the unique qualities of electricity. An undertaking can make profits by means of relatively high prices and a low turnover. The owners may be satisfied and perhaps proud of a concern of this sort, and see no need for further efforts. To embark upon a live selling organization, involving considerable additional expense and responsibilities, might cause awkward controversies.

It is possible for some undertakings to double or treble their rate of expansion by putting personnel with brains and acumen into the selling side of the business. The selling staff should be adequate in numbers as well as in competence. One good development officer should be allotted to each section of a supply area having, say, 5 000 inhabitants. His life's work should be the increase of the sales of electricity in his sub-district, and he should receive, as a minimum, £300 per annum plus commission. Thus, in connection with a supply authority having 50 000 inhabitants in its area of supply, 10 such officials would be required, all working under the control of a specialist official. The duty of each should be to obtain every year orders that will yield, say, £20 000 in the succeeding 10 years.

Such results can only come about after the drafting and putting into operation of complete schemes covering all details of organization, management, costing and Head Office routine, full co-operation with the E.D.A. local publicity showrooms and lecture rooms, the stocking of standard fittings and apparatus (changed every year or two), well-equipped repair shops, distinctive electric delivery vans, and a well-trained staff of special officials and workmen devoting all their time to the special development work.

I suggest that the most useful contribution towards a still greater rate of development would be a course of training in commercial organization to suit different types of electricity supply undertakings, designed to give those in control more confidence and to stimulate the spirit of enterprise. This would do far more to achieve the ends which the author refers to than any scheme of development based on national standard tariffs.

Mr. H. Hooper: It is important to treat statistics carefully, otherwise they may easily give a wrong impression. For instance, it would be easy for a reader to get the impression from the paper that all is not well with the electricity industry. The last annual report of the Central Electricity Board gives, however, entirely the opposite impression. It states "The progressive increase in the output of electricity from the public supply stations in Great Britain has been fully maintained. The increase of 2 650 million units in 1936 was the highest recorded in the history of the industry and brought the total production by authorized undertakers in the year to over 20 000 million units. While the progress of economic recovery gave rise to an increase in the consumption of electricity throughout the world, and particularly in the United States and Germany, it is still true to say that electrification is proceeding in this country at a greater pace than in the world as a whole. Since 1929, the output of electricity in Great Britain has increased by over 95 per cent, whereas over the same period the expansion of world production has not exceeded 35 per cent." I would also mention Mr. Forrest's recent statement that electricity supply tariffs in towns in Great Britain are the lowest in the world.

On page 429 the author says that electricity for power purposes is sold in many cases at unremunerative prices, considerably below the equivalent cost of production by private plant, and the effect of this is to place on domestic charges a burden which prohibits the domestic load from increasing to the point at which it is profitable. I suggest that this is not quite correct, because the price at which power supply is given is usually governed by the costs incurred by the undertaking in giving this supply. Tariffs must be based on costs if equity is to be ensured.

At present Diesel-engine manufacturers are " out for " an extensive campaign against public supply, and any increase in private-plant supplies would have a detrimental effect on public supply generally. Would anyone dare to advocate that power loads should not be cultivated? If the power load disappeared, the domestic consumer would have to pay more.

I see no cause for pessimism regarding domestic supply. The curve of improvement during the last 5 years has been good, and future prospects could hardly be brighter. Why classify progressive undertakings, which are generally large ones, with the relatively few not so prosperous and smaller, whose totals hardly make any difference? The domestic consumption of electricity is going up by leaps and bounds, and any fall in average consumption is due to connecting many thousands of smaller houses whose occupants have not yet become accustomed to the use of electricity. I disagree with the author that domestic prices are too high generally, although I acknowledge that they are in some few cases.

I do not support the suggestion of a standard unified tariff on which electricity would be supplied at less than cost in advance, the demand being worked up to justify the low cost by increased consumption. One of the arguments against this is the question of mains distribution troubles; I do not think that the author could state what would be the diversity factor if 1 000 cookers were installed on one small estate covering, say, 1 500 houses.

Referring to Table 9, I agree that the increase in the units sold per £ of annual distribution costs is not so rapid as one would like, but the explanation is that during the last 3–5 years the larger municipalities and distribution companies have so spread out their distribution systems, with consequent large capital outlay, that if they were now to refrain from making further extensions the units sold per £ of distribution capital would go up very rapidly. What will actually happen, of course, is that further distribution expense will be incurred for further developments.

Mr. H. Joseph: The author's curves which are plotted to represent the general tendency of some very scattered points do not seem to me to be very convincing. In Fig. 3, for example, he draws just the curve he would expect to get, but I do not think the points necessarily justify his conclusions. May I give mine, which I admit have no more justification, just to show how easy it is to jump to false conclusions? I take the lower curve and find from the actual points that as long as a rate of 1d. per unit is maintained the consumption may be anything up to 4 000 units per annum, after which a rapid fall in price down to about 0·7d. leads to an increase in consumption up to 5 000, and then a further very small decrease in price leads to a disproportionately large increase in consumption. In fact, conditions soon approach instability, when the slightest fall in price would lead to an infinitely great annual consumption.

I cannot agree with the author that domestic supplies are subsidizing power. He has been very successful in persuading power users in his area of supply to come on to the mains, and he apparently concludes, partly from his own success, that the margin in favour of a public supply is greater than it need be and that with a higher rate he would have been equally successful. Is not the problem much more difficult where process steam is used than where Diesel engines are installed? But there are other fields for industrial power, such as electric welding, electric furnaces, and chemical processes, for which extremely low running charges are essential and for which the suggested rate of 0·5d. per unit would be much too high. The author suggests introducing low rates for domestic supplies in anticipation of increased consumption—with which I am inclined to agree—yet he does not support a similar practice in dealing with power. I cannot think why he should make such a point of stressing the decreased average consumption by domestic consumers, which is obviously due to the very large number of assisted-wiring and other small consumers who have been connected in recent years. These people, whose use of the supply is for the most part confined to lighting and radio, and perhaps a domestic iron, will probably not use much more electricity for some years; but their consumption will increase as time goes on, with education, better trade, and a general improvement in the quality of electric cookers coupled with better facilities for obtaining their use on easy terms. A further reduction in running charges is not the only consideration necessary for a large increase in domestic consumption.

One of the salient points in the paper is the suggestion of a fixed " consumer charge," for which a figure of £5 per annum is put forward. I venture to submit that for cottage property this is far too high and that for a large house it is absurdly low. A better plan would be to adopt three or four rates for different grades of houses, finally putting the hotel and large store on a kVA-of-maximum-demand basis.

We have to aim to obtain (*a*) the largest possible number of consumers; (*b*) the largest possible revenue per consumer; and (*c*) the largest possible profit as a percentage on capital. To obtain all these we must offer the lowest possible tariff, based on an assumed total connection and an assumed capital cost—neither yet attained—and in doing so we must bear in mind that the loads we aim at for domestic consumers will never be carried on the present l.t. networks and that we have to face the cost of an entirely new distribution scheme with h.t. distributors.

Mr. P. B. Mair: From the start of the paper, the author has to make assumptions on fundamental points.

He is obliged to assume even the number of domestic consumers of electricity in the country, but is not able to estimate the number of units used by that important group of consumers. Reference is made throughout the paper to domestic supplies and domestic consumers but, in fact, the statistics refer to all supplies other than power, traction, and public lighting. This means that in making his calculations the author has had to attribute to the domestic consumers heavy consumptions from shop and office lighting and heating, cinema supplies, and other similar heavy loads.

The greatest potential load for the electricity supply business to-day lies in further domestic use of electricity. The rapid development of that load on an economic basis is, therefore, one of the most important problems facing the industry to-day.

The author assumes that normal developed domestic loads and industrial loads give equal system load factors. I am unable to agree that this is the case. Even from the figures quoted in Table 5 for a very small number of undertakings it is evident that the load factors of industrial undertakings are higher than those of domestic undertakings. In a wider survey I have made, I have found no undertaking selling more than half of its output for lighting and domestic supplies which has a load factor of over 40 per cent, whereas, in 1934, 57 undertakings with a large proportion of industrial load had load factors of over 40 per cent and 15 had load factors of over 50 per cent. These 57 undertakings represented by far the bulk of the electricity sales for the country. From these figures it appears that developed industrial load provides a higher system load factor than developed domestic load. I should like to mention that during the last 8 years the proportion of units sold for lighting and domestic purposes has increased from 24·4 per cent of the total sales to 34·8 per cent. In the same period the number of undertakings with load factors in excess of 30 per cent has increased from 15 per cent of the total to 43 per cent, and the load factor of the "normal" undertaking has increased from 21·8 to 28·7 per cent.

The author's ultimate conclusion depends upon (1) the proportion in which power and domestic supplies at present meet distribution costs, and (2) the additional capital investment which will be necessary to meet developing domestic load. His conclusion that the power load is at present subsidized by the higher-priced lighting and domestic load appears unsound, as his assumption of equal system load factors for domestic and industrial loads is apparently incorrect and as a very high proportion of industrial sales are delivered and metered at high voltage. The capital investment in low-voltage distribution, main substations, etc., is therefore not attributable to such supplies.

I put forward these arguments to show that from the published information available it is not possible to arrive at a sound and reliable conclusion in the matter under discussion. It is lamentable that an industry of the importance of the electric supply industry should not have available a complete analysis of sales of electricity and capital investment. In order to arrive at a satisfactory solution of the problem of the charges which should be made to produce the most rapid development of the domestic load on an economic basis it is necessary to have a complete analysis of electricity sales and capital investment, and surveys should be made of areas in which domestic load is highly developed to ascertain what diversity is obtained in practice. Such surveys should be made in various parts of the country to provide for the different habits and customs which will influence both the diversity factor and the load factor of the domestic load. Undertakings should realize the importance of having such information collected by some central body such as the Electricity Commissioners, and should therefore prepare the statistics called for by the Commissioners promptly so that the returns can be published within a few months of the end of the period under review, instead of, as at present, the latest figures being 2 years out of date.

It is not sufficient for a body such as the Electricity Commission to publish figures provided by the various undertakings in tabulated form as at present. A proper statistical analysis should be made in order to show as far as possible, from the information available, the lowest price at which it is economically sound to sell increased units for domestic supplies.

Mr. F. J. Elliott: The paper readily divides itself under three headings. In the first portion the author quotes a large number of statistics and presents graphs and figures to prove that the average consumption per domestic consumer is decreasing. I suggest that this fact needs no proof, but is the natural result of the connection to the mains of a very large number of premises in which the consumption is of the lowest order. For example, in Wolverhampton, 33 per cent of the total number of consumers are taking their supplies under an assisted wiring scheme and the consumption averages 150 units per consumer per annum. It therefore follows that the remaining domestic and lighting consumers need to increase their consumption by approximately 40 per cent in order to maintain an average consumption per consumer for the group of 800 units per annum.

In regard to the second portion of the paper, wherein the author contends and endeavours to prove that the domestic consumer is making a contribution towards the fixed cost of affording supplies to power consumers, I am afraid he will find very few to agree. In his analysis of the cost of affording respective types of supply he has apparently ignored the primary-voltage consumer taking a very large number of units. Perhaps Wolverhampton is a particularly appropriate case to quote, seeing that 70 per cent of the output is sold at the primary voltage to 0·2 per cent of the total consumers. The fixed charges which have to be met on account of capital which has been expended to afford a supply to these consumers represents only 3 per cent of the total fixed charges of the undertaking, and, in actual fact, the elimination of these consumers and the costs associated with their supplies would make it necessary to obtain an additional 0·04d. per unit from the remaining lighting and domestic and low-voltage power consumers.

I heartily agree with the remarks made by previous speakers when deploring the lack of useful available statistics appertaining to the supply industry.

With regard to the theoretical tariff put forward by the author, I am not sure whether the application of the principles suggested would not result in a fairly equitable apportionment of the fixed charges between different classes of consumer if these charges were calculated on actual facts as they exist to-day instead of upon the bases suggested by the author and arrived at by averaging mass statistics and making assumptions therefrom.

Mr. J. R. Blaikie: Referring to statistics and methods of analysis, there is a very common fallacy with reference to the overall sizes of generating stations. Table 6 shows that there is a fairly regular diminution in the price obtained with the increasing size of the station group, and it is commonly believed that the size of the station governs the price per unit. In column 9, however, we find the units sold per consumer, and it will be noticed that the growth in this value has followed the overall growth of the station. In a contribution to the *Electrician** in 1926 this question of the big stations was examined to explain the fact that a number of freak small stations produced equal results. For example, in 1924–25 the Liverpool undertaking with 132-million units was about 10 times the size of the York undertaking with 13 millions, yet both collected approximately the same price per unit. On examination it was found that both had an average of about 4 000 units per consumer, and that their load factors were nearly equal. Other cases fell into line, showing that it is the average size of the consumer and not the overall size of the station which is the dominating factor in the price of the unit.

According to Table 12 the Chester rural undertaking has produced some freak results, as there is a larger surplus in 1936 with a load factor of 38 per cent than in 1934 when the load factor was 51·2 per cent. The Mid-Cheshire undertaking also shows a better result in 1935, with a load factor of 33·5, than in 1934, when the load factor was 36·8. Do these freak results indicate that there is something wrong with the load-factor system? The author advocates the abandonment of this system, and undoubtedly the time is approaching when a quantity tariff, without regard to the purpose for which the energy is used, will be a commercial proposition.* As he points out, progress in tariffs has been extremely slow. This is partly due to the enormous prestige of Dr. John Hopkinson's load-factor system. The Norwich or rateable-value system is the only real departure from it; all that is necessary is to decrease the rateable-value component gradually and increase the unit charge slightly until one day the fixed charge can be replaced by an amount determined by large quantity steps. The policy of low unit rates is to be condemned. It is admittedly a device intended to deceive the consumer, and not infrequently leads to the selling of some supplies at too low a rate. Dr. Hopkinson warned us about using too low a unit charge, for this reason. The last thing to be desired is Government intervention, seeing that the Government has already committed itself to load-factor discrimination in bulk supplies. It is an extraordinary thing that, whilst adopting a policy of levelling-up the whole country, the Government did not consider averaging load factor and thus developing a quantity system.

[The author's reply to this discussion will be found on page 484.]

NORTH-EASTERN CENTRE, AT NEWCASTLE, 12TH APRIL, 1937

Mr. C. R. Cooper: The author's plea that some improvement in domestic consumption should be encouraged by the general adoption of tariffs providing a low unit rate is one which will have the support of many; it is on the magnitude of the component parts of such tariffs that differences arise.

It is unfortunate that the information at his disposal should have been incomplete, so far as data relative to domestic premises are concerned. It is the supply to houses with which the author is chiefly concerned, but most of the data which he uses relate to a mixture of houses, shops, cinemas, and other business premises. The following figures, which have been tabulated on a basis similar to that of Table 2, illustrate how misleading such a comparison can be; the data relate to town and suburban premises.

(*a*) *Houses only.*	
Average units per consumer ..	284
Average price per unit	2·2d.
Annual revenue per consumer ..	£2·6
(*b*) *Shops and Other Premises.*	
Average units per consumer ..	2 910
Average price per unit	1·91d.
Annual revenue per consumer ..	£23·1
Total, (*a*) + (*b*).	
Average units per consumer ..	805
Average price per unit	2·0d.
Annual revenue	£6·7

It will be noticed how close the figures for the total group are to those in the last line of Table 2, and also what little resemblance these averages bear to the correct domestic average. It is misleading to base any assumptions on the combined averages of houses and business premises if the subject of our investigation is the supply to domestic premises.

On page 445 the author quotes a tariff of £1 5s. per annum with all units at ½d. as being suitable for inducing a small consumer with a revenue of £5 per annum to increase his use. With this tariff the consumer could use 1 680 units for his £5 revenue, giving an average price of 0·715d. per unit. But if we refer back to Fig. 3 we see that the value to the consumer represented by this consumption is of the order of 1¼d. per unit, which is, I think, a more correct value.

When suggesting the general adoption of a uniform tariff composed of an annual fixed charge and a low unit rate, the author assumes that it is probable that undertakings doing so would incur an initial deficit. This need not be so, so long as a suitable tariff is adopted and, if circumstances so demand, it is introduced gradually. If the undertaking is producing only a reasonable profit with the existing average revenues and units per consumer then if a low unit rate is introduced the tariff should be so designed that it maintains approximately the same revenue for the same average consumption. The increment in consumption should earn the lower rate. While the possibility of a retrogression of annual consumptions is probably remote, any tariff adopted for universal application should preferably allow for such a contingency, which may be brought about by trade depression or even by the introduction of more efficient apparatus.

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* *Electrician*, 1926, vol. 96, pp. 230 and 436.

* See *I.M.E.A. Journal*, 1935, vol. 5, pp. 15 and 30.

The fixed-charge and low unit-rate tariff is a satisfactory method of charging, and has much to commend it. There are, however, always the few consumers who object to paying a fixed charge in any form; for these as well as for the consumers who do not wish to use electricity for any purpose other than lighting, there must always be an alternative tariff. To insist upon a fixed-charge tariff in every case would in certain circumstances place one in the position of charging more than the authorized maximum price. Such an alternative tariff should be so designed that it encourages the small consumer to increase his use up to a point where it is to his advantage to change over to the fixed-charge tariff. A sliding-scale unit-rate tariff having the last step of the tariff at the same unit rate as the fixed-charge tariff is most suitable for this purpose. Neither the fixed charges nor the unit steps of the alternative tariff need, however, be the same for all consumers. The demands which are made at the times of maximum demands on the substations and the power stations vary with the size of house, and it is these demands which determine the size of distributor which is necessary to give an efficient supply. As the author points out, the capital value and annual costs allocable to distribution form an appreciable portion of the total charges, and this alone is an argument in favour of graded tariffs.

Standardization of tariffs throughout the country would undoubtedly be a step in the right direction, but I do not think it could be achieved by the proposed financial co-ordination, which is impracticable and unnecessary. To make tariff standardization possible, standard costing methods must be introduced. While it is true that a tariff need not exactly fall into line with the costs, the more closely the two are allied the more stable will be the tariff. Uniform costing has been adopted in many other industries, and conditions in different electric supply undertakings in this country are now sufficiently similar for a uniform costing system to be introduced. To attempt to devise a tariff by rule-of-thumb methods would advance the industry little farther than has been done by these same methods in the past. If we are to study component costs in a rational manner we must firstly ascertain that there is a relationship between the items we are attempting to correlate. As an example of this may be quoted Table 13, where distribution costs per consumer for domestic and power consumers are arrived at by dividing the total cost on a unit basis. There is no simple relationship between distribution costs and units, and there can thus be no justification for such an arbitrary division. Furthermore, these distribution costs include, presumably, both high- and low-voltage distributors, and I can find no logical reason for charging repairs and maintenance of low-voltage networks against power consumers who are not connected to these networks.

Such basis of reasoning does not justify either the tariffs derived from Table 13 or the assumption that power rates are low and are being subsidized by domestic rates, as appears to be the purpose of the second part of this table.

Mr. F. A. Orchard: I should like to comment on the lack of development amongst consumers who use electricity for minimum purposes, to which the author refers for the period 1927–35. During this period a large number of slum-clearance and other housing schemes have been in operation in many parts of the country, causing the setting-up of extensive housing estates in which both gas and electric supplies have been laid at high capital costs to small houses where the majority of tenants have had to exist on unemployment benefit. In many instances these tenants have been using electricity for operating a wireless set only, and in some cases for one electric light in addition. Such users unfortunately contribute to the annual statistics of additional consumers, and I suggest that the proportion of new consumers of this order throughout the country is by no means small. As an example of this I may say that the company with which I am connected have found it necessary during the past 5 years to lay cables and services to some 6 estates under municipal schemes covering some 3 000 consumers and entailing some £54 000 capital expenditure. The average consumption per head of tenants of such estates is 91·5 units, at an average revenue of £1 14s. 3d. Although this return is small and unprofitable one may safely assume that with the improvement in labour conditions and increased spending power through workers coming off unemployment benefit a better return will be indicated during 1937. There is, however, the competition with gas where dual supplies have had to be given in accordance with the requirements of the municipal authorities.

Mr. W. A. Royle: In Table 1 the author has taken the data from the engineering and financial statistics issued by the Electricity Commissioners, using the units shown as lighting, heating, and cooking load, and has further assumed that the figure of 835 units for domestic supplies was correct for the year 1930–31. Unfortunately for the author this figure is not correct, and was not accepted by the electricity supply industry, nor are the other figures set out in Table 1, because these figures are the total of the combined heating, lighting, and cooking units sold and include all the lighting and heating in business premises.

The results for Sunderland, which can be taken as being a fairly representative town, are given in Table E on the same basis as that of Table 1. It will be noted that in 1930–31 the consumption as given by the author's method of calculation was 922 units per consumer as against the assumed average of 835, and that in 1934–35 the consumption was 873, as against the author's figure of 765 units. Sunderland is a progressive undertaking judged by the author's standards, and as it comes in the 50- to 100-million group this average consumption of 873 units per consumer for 1934–35 practically coincides with the author's figure. This, I think, proves that Sunderland is an average undertaking, and that if the author's figures as applied to Sunderland are wrong they are equally wrong for all other undertakings.

Table E shows the position of domestic consumption in Sunderland, and indicates that the average consumption per consumer in 1934–35 was 432 units. The Darlington undertaking have for years been selling electricity at very low charges, probably the lowest in the country, but their annual report shows that the consumption per domestic consumer is far below that assumed by the author. According to him, small undertakings selling below 10 million units with an average of 378 units are grossly under-developed. Why then, in the case of these two undertakings selling electricity at the rates he suggests, does the consumption fall so far below his figure?

Turning to Table 2, why in col. 3 has the author only scheduled the results of 549 undertakings, whereas the Electricity Commissioners' return refers to 626? Out of 189 undertakings selling less than a million units, the author includes 184 in his schedule; out of 240 undertakings selling between 1 and 10 million units he schedules 203, between 10 and 25 million units he schedules 66 out of 75, and between 25 and 50 million units he schedules 48 out of 75; but over 50 million units he only schedules 48 out of 65 undertakings. Will the author state why he omits to schedule the other 17 undertakings?

I would refer to col. 9, Table 2, showing the average annual consumption per domestic consumer in each group, as this is the basis of all the author's conclusions. I entirely disagree with these figures, as they are not the consumption for domestic supply purposes but include shop lighting and hotel lighting and heating. I have looked through the annual reports of several of the more progressive undertakings selling over 100 million units per year, and can find no evidence that any of these undertakings are selling 915 units per domestic consumer. I suggest that a close scrutiny of the correct figures would show that, even to-day, the average consumption per domestic consumer for the whole country is between 500 and 600 units per year. The tendency, mentioned by the author, for the consumption per domestic consumer to fall, is bound to be evident irrespective of the selling price, owing to the connecting-up of large numbers of working-class houses. Even with electricity at ½d. per unit, the consumption in a working-class house will not exceed 500 units per consumer per annum, unless cookers, wash boilers, water heaters, etc., are hired at uneconomic prices.

A scrutiny of Table E shows that, of the 17 183 domestic consumers in Sunderland, 1 500 still remain on the general lighting rate with an average consumption of 200 units at 3½d. per unit. 2 500 consumers have remained on the old domestic rate at 12½ per cent of the net rateable value and ½d. per unit, and use an average of 887 units per annum, at an average price of 1·42d. The reason why these consumers have not changed over to the "electric home" tariff is because they are mostly occupying 4-roomed houses in a part of the town where the assessment of this class of house is £14; this gives them a fixed charge of £1 15s., whereas if they changed over to the electric home tariff their fixed charge would be £2. On this tariff we have 5 500 consumers using approximately 5½ million units with an average price of 0·783d. per unit, and an average con-

Table E.—Domestic-Consumption Figures for Sunderland Corporation Electricity Undertaking

Year	Analysis based on Electricity Commissioners' Return (lighting, heating, and cooking units) used by author as basis for his conclusions					Actual position			
	Units for lighting and all domestic supplies	Consumers	Domestic consumers*	Units per domestic consumer	Average price (d.) per unit	Units	Consumers (domestic)	Units per domestic consumer	Average price (d.) per unit
1927–28	4 838 000	8 379	6 870	704	3·66				
1928–29	5 966 000	9 115	7 476	798	2·90				
1929–30	6 853 000	9 970	8 175	838	2·54				
1930–31	7 994 000	10 576	8 672	922	2·44	3 468 115	7 875	440	2·006
1931–32	8 040 000	11 507	9 434	852	2·46	4 123 878	9 925	415	1·97
1932–33	9 353 000	12 480	10 237	916	2·38	4 361 639	10 904	400	1·94
1933–34	9 585 000	13 650	11 195	856	2·26	5 250 290	12 159	432	1·76
1934–35	10 730 000	14 987	12 290	873	2·06	7 070 896	13 870	510	1·376
1935–36	13 197 000	17 015	13 955	943	1·70	10 702 528	17 183	623	1·13
1936–37	16 821 000	20 700	16 975	990	1·47				

Analysis of actual sales to domestic consumers				
Number of consumers	Tariff	Units	Average units per consumer	Average price (d.) per unit
1 500	General lighting rate: 3½d. per unit	300 000	200	3·50
2 500	Old domestic rate: 12½ % net rateable value, ½d. per unit	2 219 559	887	1·42
5 500	Electric home tariff: 2s. 6d. per room per quarter, ⅓d. per unit	5 459 245	993	0·785
6 528	Assisted wiring as elec. home tariff, plus hire and maintenance of installation†	2 123 561	325	1·39
1 155	Corporation houses, as elec. home tariff plus maintenance†	600 163	520	1·07
17 183		10 702 528		1·13

* On the assumption that domestic consumers form 82 per cent of the total.

† Average price, electricity only.

sumption of 993 units per consumer. The next two classes of consumer are interesting. These consumers obtain their electricity at exactly the same rate as the electric home tariff consumers, but the consumption averages 325 units per consumer in the case of assisted-wiring consumers and 520 units per consumer in the case of the Corporation houses. These figures indicate that it is not the price they are being charged or the lack of hire facilities that is restricting the use of electricity by these consumers, but it is a question of economics: they cannot afford to use more on a wage of £3 per week.

I agree with the author's statement regarding the connecting-up of a large number of consumers on the slot-meter assisted wiring scheme. The summary I made in 1931 of all the assisted wiring schemes in the country showed that the average consumption per slot-meter consumer was 85 units. In Sunderland, but in the supply company's area, the average consumption of consumers supplied through slot meters at 4d. per unit is not more than 90 units per year. On the other hand, the municipal undertaking obtains from a similar class of consumer an average consumption of 520 units through the Corporation house tariff operated on the weekly collection system. More consideration should be given by electricity undertakings to supplying this class of consumer on an all-in charge collected weekly.

Table F shows that a supply authority of the size of the Sunderland Corporation undertaking would have to be prepared to provide a capital of £1 million in order to develop a working-class domestic load, and even on the basis of the very low hire charges in vogue in Sunderland, with electricity at ½d. per unit, the cost to the consumer would have to be 2s. 11½d. per week, which is approximately what E.D.A. Report No. 1288 estimates this class of consumer could afford to pay. No undertaking would contemplate borrowing such a large amount for hire and hire-purchase. A development of this kind can only be undertaken economically in stages, by first connecting consumers up for lighting and small uses, and obtaining an average price in the region of 1½d. or 2d. per unit; and using the resultant surplus to finance out of revenue the purchase of meters, and hire and hire-purchase schemes.

Table 5 is interesting. I would suggest that towns Nos. 1 to 6 cannot be classed as more progressive in domestic development than many manufacturing towns, such as Nos. 7 to 12. The real reason for the consumption figures given for Nos. 1 to 6 is that there is no power load and the amount of light used in shops, large hotels, and boarding houses bears a different relation to the domestic units from that prevailing in a manufacturing town. This factor has thrown the author's assumptions even farther out than in Table 2. With regard to Nos. 7 to 12, I do not support the suggestion that these undertakings are selling power units at too low a price. A knowledge of local conditions would, I am sure, alter the author's opinion.

Table F

ESTIMATED CAPITAL COST OF DOMESTIC CONSUMPTION TO 2 300 UNITS PER CONSUMER PER ANNUM, BY ASSISTED WIRING SCHEME AND HIRE OF APPARATUS, FOR 28 000 HOUSES RATED BELOW £15 AND 10 000 HOUSES RATED OVER £15

Item of expenditure	Estimated cost (£) per consumer	Total cost (£)	Estimated consumption (units) per consumer	Cost to consumer*		Remarks
				Hire and maintenance	Electricity at ½d. per unit	
28 000 *houses below* £15 *net rateable value*						
Service and meter ..	5	140 000	—	—	—	
Electrical installation .. (5 lights, plug, iron, lamps and shades)	6·5	182 000	200	13s.	8s. 4d.	Total cost to consumer, £7 14s. 10d. per annum = 2s. 11½d. per week
Electric cookers with circuit and kettle ..	15	420 000	1 400	£1 6s.	£2 18s. 4d.	
Wash boiler and circuit ..	4	112 000	250	10s.	10s. 5d.	
Fire and circuit, intermittent use	3	84 000	450	10s.	18s. 9d.	
		£938 000	2 300	£2 19s.	£4 15s. 10d.	
10 000 *houses above* £15 *net rateable value*						
Cookers and wash boilers	19	£190 000				
	Total ..	£1 128 000				

* Based on Sunderland Corporation charges.

With regard to the question of the economic cost of power supplies, the position is that the consumer, who, the author states, could generate for himself with Diesel plant at 0·9d. per unit, is paying approximately 0·9d. to the undertaking; but, owing to the fact that there are a number of very large consumers connected to the supply, such as flour mills, glass works, and collieries, running with a load factor of approximately 60 per cent, they obtain their supply for between 0·4d. and 0·45d. per unit, and large off-peak power supplies for furnaces obtain their supply at below 0·4d. per unit.

Mr. E. C. Lennox: The author's figures for average domestic consumption, such as those shown in Table 2, including as they do the consumptions of such premises as cinemas, large stores, hotels, and possibly street lighting, would be reduced considerably if recalculated on the basis of consumption per purely domestic consumer. Such a figure would be anticipated to be not more than 30 per cent of that shown in the author's tables.

There is also no doubt that the many small consumers connected during the last 10 years have caused the decrease in the average consumption per consumer shown by the author. It is interesting to have his suggestions as to how to improve the annual average consumption, and I agree that the introduction of a standard and reduced tariff of the two-part type should have an improving effect; but it should be remembered that this small class of consumer presents other difficulties, such as the collection of monies. Of what use is it to suggest a fixed charge and a small unit rate for these small consumers (and they represent some 30 to 40 per cent of the total in an industrial area) if the supply authority is unable to collect monthly or quarterly accounts? Such consumers need high capital outlay in the provision of prepayment-type meters, and this additional capital with the additional cost of collection will have the effect of increasing the distribution costs per consumer.

In his verbal summary of the paper the author suggested that service should be given to all premises in rural areas free of service charge; this would surely result in a very high capital expenditure which could not be justified by the consumption and revenue obtained. Such a scheme would result in the influx of a considerable number of small consumers, which, with the large capital outlay involved, would still further reduce the figures shown by the author.

I agree with Mr. Royle that the consumption of 2 000 units per consumer per annum suggested in the paper can only be obtained by the installation of costly apparatus in each consumer's premises, and it is the provision of this apparatus which will present the major problem. Such apparatus as cookers, radiators, water heaters, etc., will require an outlay that the small consumer of this type is unable to afford on a straightforward hire basis, including redemption, interest, and maintenance charges, and it would seem to be a problem calling for undertakings to put up the capital necessary to provide such hiring appliances. Such a subsidy would appear to be more profitable to undertakings than the expenditure of large sums of capital in providing supplies to unremunerative consumers in rural areas.

I should also like to emphasize the point mentioned by Mr. Cooper, in dealing with the suggested co-operative financial control and unified tariffs. Excellent though this suggestion is, it would seem that before this is brought about it is necessary for some authority to insist on a unified costing system throughout the industry. Such a system would result in the production of data calculated not only to prove the necessity and advantages of unified tariffs and co-operative control, but also to bring these into operation.

Mr. T. D. Oswald: The amount which an undertaking charges any class of consumer should be the cost of production and distribution, plus the appropriate capital charges for the plant involved and managerial and similar costs. Most undertakings adopt a definite system which enables various classes of consumer to be assessed with their appropriate proportion of the above costs. The system adopted by the Central Electricity Board divides the cost into two parts, one proportional to the kilowatts of maximum demand and the other proportional to the units sold. Under present conditions of coal price, wages, etc., these are of the order of £3 10s. per kW of maximum demand, plus 0·25d. per unit sold. The costs of further distribution may be allocated on a similar basis by using a scheme like that expounded by Messrs. Woodward and Carne.* For a company undertaking selling about 30 million units per annum the Central Electricity Board charges and further costs may be satisfactorily expressed as:—

High-voltage consumers: £4·95 per kW per annum at time of high-voltage maximum demand, plus 0·262d. per unit, plus £1.

Low-voltage consumers: £5·20 per kW per annum at time of high-voltage maximum demand, plus £10·25 per kW per annum at time of low-voltage maximum demand, plus 0·292d. per unit, plus £1.

In applying these figures to individual consumers it is necessary to allow for the fact that the aggregate of individual maximum demands will be less than the actual total maximum demand by reason of the diversity of times when each maximum demand is incident.

Present-day values of diversity, as determined by the company with which I am associated, have been used in compiling Table G, which refers to an individual consumer in each case. The high-voltage power consumer is given such preferential rates for several reasons: (1) He does not require a low-voltage network, which is seen to be responsible for the greater portion of the costs to domestic consumers. (2) His requirements do not vary widely from summer to winter. (3) He is willing to refrain from using electricity during maximum-load periods; e.g. the consumer quoted in the last item in Table G had a maximum demand of 700 kW during the night, which intentionally avoided the high-voltage peak-load period. It is this class of power consumer, using large blocks of power at low yet economical rates, which is responsible for the low average rate for power.

In the case of domestic consumers, consumptions of the order of 1 000 units per annum yield a profitable return. Small consumers using less than 100 units per annum are supplied at a considerable loss. This type of consumer is invariably found in slum-clearance and similar housing estates, with tenants in poor circumstances. The connection of many thousands of these houses has been forced on undertakings in this district and throughout the country, and until employment conditions improve they will continue to prove a serious loss to supply authorities. It is the connection of this class of consumer which is largely responsible for high rates to domestic consumers and the rise in distribution costs and capital expenditure commented upon by the author.

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* *Journal I.E.E.*, 1932, vol. 71, p. 852.

Table G

Type of consumer	Installed kW	kW on high voltage	£ per annum	kW on low voltage	£ per annum	Units per annum	£ per annum	Consumer charge (£) per annum	Total £ per annum	Theoretical d./unit	Actual d./unit
Prepayment	0·15	0·025	0·124	0·05	0·510	80	0·098	1	1·732	5·2	4
Small lighting ..	0·55	0·047	0·232	0·094	0·962	170	0·207	1	2·401	3·4	2·92
Medium lighting, etc.	2·20	0·195	0·965	0·396	4·000	775	0·945	1	6·910	2·15	2·37
Small house, full electrical equipment ..	20·0	1·80	8·90	2·50	25·60	9 500	11·60	1	47·10	1·20	0·85
Large house, full electrical equipment ..	23·22	2·34	11·60	3·06	29·8	18 468	22·5	1	64·9	0·84	0·76
High-voltage power consumer	—	300	1 480	—		1 980 447	2 170	1	3 651	0·44	0·47

Referring to Table G, in the case of the large house with full electrical equipment the units consumed fell under the following heads: heating 8 553, cooking 2 536, water heating 6 465, lighting, etc., 914; total 18 468. It will be seen that heating constitutes a considerable portion of the whole, and, while cooking and water heating are maintained throughout the year, space heating occupies a much shorter period. Moreover, from the characteristics of this class of load it is evident that all heating consumers will require their supply simultaneously. In practice it is found that the diversity factor of the heating load is poor. An encouragement of heating will result in two effects: firstly, the diversity of domestic consumers will decrease; and, secondly, the shape of the load curve will be altered and the domestic consumer will become responsible for a greater proportion of the maximum demand than he is now. Both these effects will increase the proportion of the total costs with which the domestic consumer will be charged. Whether the increase in load will result in a sufficient decrease in cost to counterbalance the above effects is a matter of opinion. As a radical change in character of load is being faced the extension of past records may not give reliable information.

THE AUTHOR'S REPLY TO THE DISCUSSIONS AT LONDON, LEEDS, EDINBURGH, BIRMINGHAM, AND NEWCASTLE

Mr. J. A. Sumner (*in reply*): Before replying to the discussions which have taken place during the 1936–37 session I wish to thank those contributors who have helped considerably in the consideration of the factors of cost which are being discussed by bringing forward some valuable criticisms and suggestions.

GENERAL REPLY

I should like to commence the general reply to the discussions by confirming Mr. Simister's view that the paper should be considered from a national standpoint and not from a local or individual standpoint. Several speakers have suggested that it would have been better to confine the analysis to the results of a few progressive undertakings, but I cannot agree that this course would have been as valuable as the consideration of the averaged values for the whole of the national electricity supply industry.

The Value for the Average Domestic Consumption

A large amount of attention has been directed to the first portion of the paper, which makes an analysis of domestic consumption. This analysis is criticized because the consumption of shops, hotels, offices, etc., is included under the heading of "domestic consumption" and it is suggested that the consumption for houses only should have been considered under this heading. I would explain that it was not possible to make this subdivision for the country as a whole owing to the complete absence of the necessary statistics. It is unfortunate that a large and important industry such as that of electricity supply is not in possession of data which show these elementary statistical divisions, and I have reason to think, in reply to Mr. Waite, that the Electricity Commissioners have not been able to obtain reliable information of this nature from many of the supply undertakings, although such information is urgently needed.

There has also been considerable criticism of the statement, made in the paper, that the average consumption per domestic consumer in the whole country is stationary or probably declining, but I do not find that any proof has been submitted to show that this statement is incorrect. The data of true domestic consumption which have been produced for certain of the larger undertakings actually prove this thesis true, as at Sunderland (Table E, col. 9) where there was a decline from 1932–35, and at Hull (Table B, col. 10) where the domestic consumption has been practically stationary since 1933; and also at West Ham where there was a decline from 319 units to 286 units between 1926 and 1934.

The discussions therefore point to the fact that the figure of averaged true annual domestic consumption, i.e. the consumption in the household, is considerably lower than the figure of approximately 800 units which I have shown in Table 1. Mr. Royle puts the figure at between 500–600 units and Mr. Lennox at about 250 units, while Mr. Cooper instances 284 units, and it would seem that an annual figure of true domestic consumption, averaged for the whole country, would be not more than 400 units.

Reasons for the Decline in Average Domestic Consumption.

The feature of the discussions which occasions some surprise is that the speakers who have been the most severely critical of my " pessimism " in suggesting that the average domestic consumption is low and that it is stationary or even declining, join with the majority of the other speakers in stating that a decline in average domestic consumption is to be expected; they also join in providing reasons which explain this decline. The connection, during recent years, of large numbers of the poorer class of household is the chief reason which is advanced. But it is difficult to see why the connection of the poorer class of house should result in a decline in average consumption, unless it is conceded that this class of consumer uses only a small quantity of electricity for the minimum purposes and does not subsequently increase its annual consumption (see para. 2, page 429). Apparently this point, which comprises the main thesis of the paper, is conceded to me and it is then of some interest and value to examine the reasons put forward in the discussions to account for the constantly low annual consumption on the part of such a large proportion of the domestic consumers, and to see how far these reasons coincide with those which I have put forward in the paper to explain the static condition of the domestic supply.

Mr. Allen and Mr. Waite suggest that a more developed commercial organization and development are required to accelerate progress, but the greater number of speakers agree that domestic development can only be increased in the poorer class of household by the supply undertaking investing money in supplying consumers with the consuming apparatus, a view which was stated in an admirable manner by Mr. Beauchamp during the London discussion. I am in full agreement that action on these two points is very urgently required, but I would also point out that the amount of money which would be required to provide the necessary consuming apparatus would amount to many millions of pounds (see Mr. Royle's illustration of investment required for the Sunderland undertaking, and the estimate by Mr. Pass of £132 million). I think that it is unlikely that we shall obtain the necessary development of expenditure on these lines until a closer co-ordination in development and finances is achieved between supply undertakings. Further, the development on these two important lines must necessarily be slow in producing results and it will be many years before any tangible effect can be produced. But I think it will be agreed that progress in increasing consumption will not be made, even if the above desiderata were fulfilled, unless the price of electricity is low enough to be competitive with alternative forms of energy and until all bewilderment and suspicion with regard to tariffs is removed from the consumer's mind. Mr. Allen is quite correct when he states that a prime necessity for success is an organization for selling electricity, but any organization, to be successful, must have reasonable conditions under which to work, and there must be a " will to buy " on the part of the consumer as well as a " will to sell " on the part of the retailer. If there were a uniform national tariff (i.e. basis of fixed charge), and a uniform secondary charge promulgated for all classes of normal consumption, the sales organization would be able to commence work under extremely favourable conditions and with most of the bewilderment and doubt removed from the minds of the consumers. My experience with consumers does not coincide with that of Mr. Bernard, who finds that complaints from consumers of the high costs of electricity have entirely disappeared. I find also a large amount of misunderstanding and bewilderment among consumers who have heard of some of the many forms of tariff that are in vogue and who also observe wide differences in charges, even in their own locality. I consider that if these anomalies were removed and a standardized national charge made available, the industry would have no more need for advertising than occurs in the case of certain other commodities which are even less necessary than electricity to modern living.

Rational Basis of Charging for Electricity

A number of speakers have stated that the rational basis of charging for any commodity or service should be the cost of providing supply, and they imply that this cost will vary with each undertaking and each consumer. Another speaker (Mr. Bolton) suggests that it is equally rational to base a tariff on what electricity is worth to the consumer, as on what it costs. A rational basis of charge is, by definition, one which conforms to reason and is not absurd or extravagant, and I maintain that the strict adherence to either basis of charge would lead in certain cases to a most irrational position; most of the main changes in tariffs during the past forty years have been made in an attempt to avoid the irrational positions into which undertakings have been led by too strict adherence to either one or other basis of charge.

I cannot agree that it is rational to attempt to charge each domestic consumer on a strict and logical basis of cost, for the very simple reason that the true cost of electricity cannot be obtained. Let us examine the question of cost at the first and most simple stage, at the outgoing terminals of the generating station. Probably the most careful and advanced analysis of the cost at this early stage of supply is contained in the Memorandum issued by the Electricity Commissioners in order to assist owners of selected stations to complete the Form OR.3 which is required by the Central Electricity Board, but I have yet to find that there is any large measure of agreement with this memorandum, or with any other analysis of a similar nature, as is instanced by the discussions which are taking place between the C.E.B. and supply undertakings with regard to costs under Sections 7 and 13 of the 1926 Act. At any point beyond the generating station terminals, the cost of electricity becomes increasingly obscure because of the number of new factors which have to be brought into the allocations, and even if the true cost were obtainable it would vary for each consumer. The " value " of electricity to the consumer is even more difficult to ascertain and is infinitely more variable for each consumer than the cost. If, therefore, we are to adopt a *rational* basis of charge we must move towards an arbitrary basis, i.e. towards a basis which is exercised according to discretion rather than by scientific principle.

A Uniform Domestic Tariff

I have suggested in the paper that a uniform domestic charge could be made by means of a " fixed annual consumer charge " and a secondary charge per unit for normal domestic purposes common to all undertakings and equal to ½d. per unit. There has been a wide range of discussion over this suggestion, covering the following main features and lines of criticism:—

(1) The proposal introduces still another method of fixed charge.
(2) The fixed annual consumer charge would have no relation to his demand or to the cost of providing his supply.
(3) The average fixed charges which would result would be prohibitive to the small consumer if they were made uniform.

I would answer these points by briefly re-stating the argument which is advanced in the paper. It is suggested that the rate of consumption for domestic purposes is stationary or declining and that the most urgent need in order to stimulate consumption quickly is to adopt a two-part tariff consisting of a uniform basis of fixed charge and a secondary unit charge which is common to all undertakings. It is clear that a condition of such a tariff and charge being imposed would be that it should not cause any immediate alteration in the income to supply undertakings from domestic consumers and that it should not alter, during the initial stage, the total cost per unit which consumers are now paying. Each of these conditions could be met if the fixed annual consumer charge suggested in the paper were adopted. The practical steps which would require to be taken would be for the suggested central executive body to declare an appointed day upon which all domestic flat rates would cease for normal l.t. domestic supplies and all domestic consumers would commence to be charged on a two-part basis. The fixed annual consumer charge would be made equal to the consumer's annual payment to the undertaking (averaged over, say, the last three years) less an amount equal to the average annual unit consumption when charged at ½d. per unit. The effect would be to introduce a fixed consumer charge which would vary with each consumer and would, in many cases, be as low as £1, rising in other cases to a much higher figure. The secondary unit charge having thus been made uniform in amount, the movement towards a uniform fixed charge would be made by arranging that future reductions in tariff would consist of reductions in the higher fixed charges.

The above suggestions do not introduce a further basis for deriving the fixed charge. They embody an acceptance of the existing charge to consumers as being roughly equivalent to the present cost of providing them with supply and the offer of all additional consumption at the highly promotional rate of ½d. per unit.

In reply to the suggestion that the fixed annual charge on the above basis would bear no relation to the consumer's demand, I am of the opinion that such a demand charge is no longer practicable. For the small domestic consumers, who comprise the major portion of consumers, their kilowatt demand charge is usually only a small proportion of the annual cost of providing the supply. The real demand charge to the average domestic consumer consists of the fixed annual charges in respect of loan charges, rent, rates, and taxes. The habits of consumers are practically fixed and vary only within small limits, e.g. for an undertaking which has a system load factor of, say, 30 per cent, a tremendous alteration in consumers' habits would be required to effect a reduction to, say, 20 per cent; on the C.E.B. tariff this would only vary the total cost per unit by 0·16d.

In reply to the third point, it should be noted that it is not suggested that the annual fixed consumer charge could be made uniform at this stage; this is an ideal which cannot be reached for some years. The uniform average charges which are derived in Tables 13–16 are hypothetical ones which were given to indicate the practicability of a uniform tariff and secondary charge. But it will be seen from Fig. 9 that it should be possible, within the next five or six years, to obtain uniformity in the averaged fixed annual charge at a very low figure, probably as low as £2 per consumer.

I should like to make an acknowledgment to Mr. Fennell for the suggestion that secondary charges could be made uniform without causing undue disturbance in existing revenues if the adjustment were made in the fixed charge.

Charges for Power Supplies

Many contributors appear to have misinterpreted the view which I have put forward with regard to power charges. I do not suggest that the average charge for power should be *increased* but rather that the average charge for domestic supply should be *decreased* more rapidly until it approximates to the level of the power charges. I have maintained that a traditional differentiation should not be made between the charges for domestic and power supplies, as this differentiation belongs to the early days of supply, when the average domestic consumption consisted almost entirely of high-demand, low-consumption lighting which provided extremely low system load factors. In order to justify these suggestions I have put forward the view that a consumer *with a developed domestic supply* has characteristics which are equally (or more) valuable to the supply authority than the load characteristics of the power consumer, and the main purpose of the paper has been to suggest that it would be to the advantage of supply undertakings to reduce their domestic charges in advance of the increase in consumption. They would then obtain the benefits of the improved domestic load characteristics in reducing the costs of the general supply.

There has been considerable opposition to these views during the discussions for reasons which are briefly summarized below.

It is stated that the offer of lower prices for the power load is justified because the power consumer has a better load factor than the domestic consumer. I would point out, in reply to this argument, that many of the smallest domestic lighting consumers have an annual load factor of 20 per cent, whereas the average factory working a 48-hour week will usually have a load factor of from 17 to 23 per cent. If this particular question is considered as it should be, from the point of view of the grouped system characteristics of the respective supplies, I think that the values shown in Table 4 for domestic supplies indicate that the advantage in cost should be with the domestic consumer. The results shown in Table 4 would certainly be improved if domestic supplies were encouraged to even medium development.

It has also been mentioned that power consumers generally take supply from h.t. secondary mains and that the elimination of l.t. distribution costs will therefore justify a lower price for h.t. power supplies than for l.t. supplies. (This argument ignores the fact that l.t. supplies for power are usually offered at flat rates which are usually equal to one-third of the flat-rate charges for l.t. domestic supplies.) I would like to point out that the choice of l.t. distribution for domestic consumers is the choice of the supply undertakings and not of the consumers.* It is a choice that was made necessary because of the low average domestic consumption which, in its turn, was caused by supply undertakings charging high prices for domestic and non-power supplies. The view which has been put forward during the discussions is quite correct, and I fully agree with it, i.e. that the power load is a basic load and that the high proportion of units sold for power assists to reduce the average cost per unit sold for all purposes and thereby justifies low charges being offered for power supplies. But I have maintained that the same advantages are inherent in the domestic supply, probably to a greater degree, and that the reduction of the average charge for domestic supplies nearer to the level of the average charges for power supplies would increase the domestic consumption and thereby provide benefits which are more than comparable with those obtained from the power supplies. It is certain that h.t. distribution will have to replace l.t. distribution for domestic supplies when there is any radical increase in this type of load. The use of l.t. distribution undoubtedly means that there is a higher cost for providing l.t. than h.t. supplies, but I maintain that a fair and correct allocation between l.t. and h.t. consumers of the charges for h.t. mains would often result in a much smaller difference than exists at present between h.t. and l.t. charges.

I have tried to indicate in the paper that the developed domestic load has a much higher diversity than the power load, and also that the power load is not bearing its correct proportion of the costs of distribution. I would suggest that the power consumer and the supply industry are influenced in the determination of power charges more by the very strong traditional view that electricity for power purposes must be "cheap" than by a true allocation of the costs of providing that supply.

This leads to the suggestion which is made in the paper, that public supply power charges are determined primarily so as to be competitive with the cost of power obtained from private plant rather than by a strict application of true costing methods. This comparative method of deducing charges must obviously prove to be injurious to the supply industry unless there is an assurance that the competitive price which the public supply must offer is at least equal to the truly ascertained cost at which it can provide the power supply. The competitive method of determining charges must depend also upon the true ascertainment and production by the power consumer of private plant costs and will obviously be subject to intensive bargaining on the part of the power consumers who are highly organized, through various Associations, for this purpose. This is why I have suggested that an exhaustive and authoritative examination of private plant costs by the supply industry is a vital and very urgent requirement. My chief object is to show that if low prices are being granted for power supplies at the expense of domestic supplies the result is to hinder the development of the valuable characteristics of the domestic load and thereby to defer the lower charges which would eventually result to both power and domestic consumers.

I have reproduced, in Fig. E, two curves which were shown during the discussion, since these curves epitomize all of the points which are put forward in the paper. The two upper curves show the relationship between the charge per unit, averaged for the whole country for each year since 1921, and the total sales for the whole country in each year for the combined lighting, heating, and cooking supplies and for power supplies, respectively. It will be noted that, for lighting, heating, and cooking supplies in particular, the points approximate very closely to a smooth curve which permits of a value being given to the relationship between charges and consumption. The values of the equations to the curves are as follows:—

Average charge per unit sold for lighting, heating, and cooking supplies

$$= 1\cdot63\text{d. per unit sold} + \frac{2\cdot67 \times 10^9 \text{ (pence)}}{\text{Units sold for lighting, heating, and cooking}}$$

Average charge per unit sold for power supplies

$$= 0\cdot26\text{d. per unit sold} + \frac{2\cdot6 \times 10^9 \text{ (pence)}}{\text{Units sold for power}}$$

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* Distribution to domestic consumers was carried out at high tension in the early days of supply by several supply undertakings.

It will be noted that, due to the increasing sales, the cost per unit under the second term of the equation has fallen from 4·76 pence in 1921–22 to 0·486 pence in 1935–36, for lighting, heating, and cooking supplies.

The curves in the upper portion of Fig. E were shown during the discussions to demonstrate the greater elasticity of demand for combined lighting, heating, and cooking supplies than for power supplies, i.e. that for a given amount of increase in sales the increase in income was proportionately greater from lighting, heating, and cooking, than from power supplies. This may be seen by using the above equations to obtain values for the total revenue from supply. The relation for total revenue between the two types of supply is then as follows:—

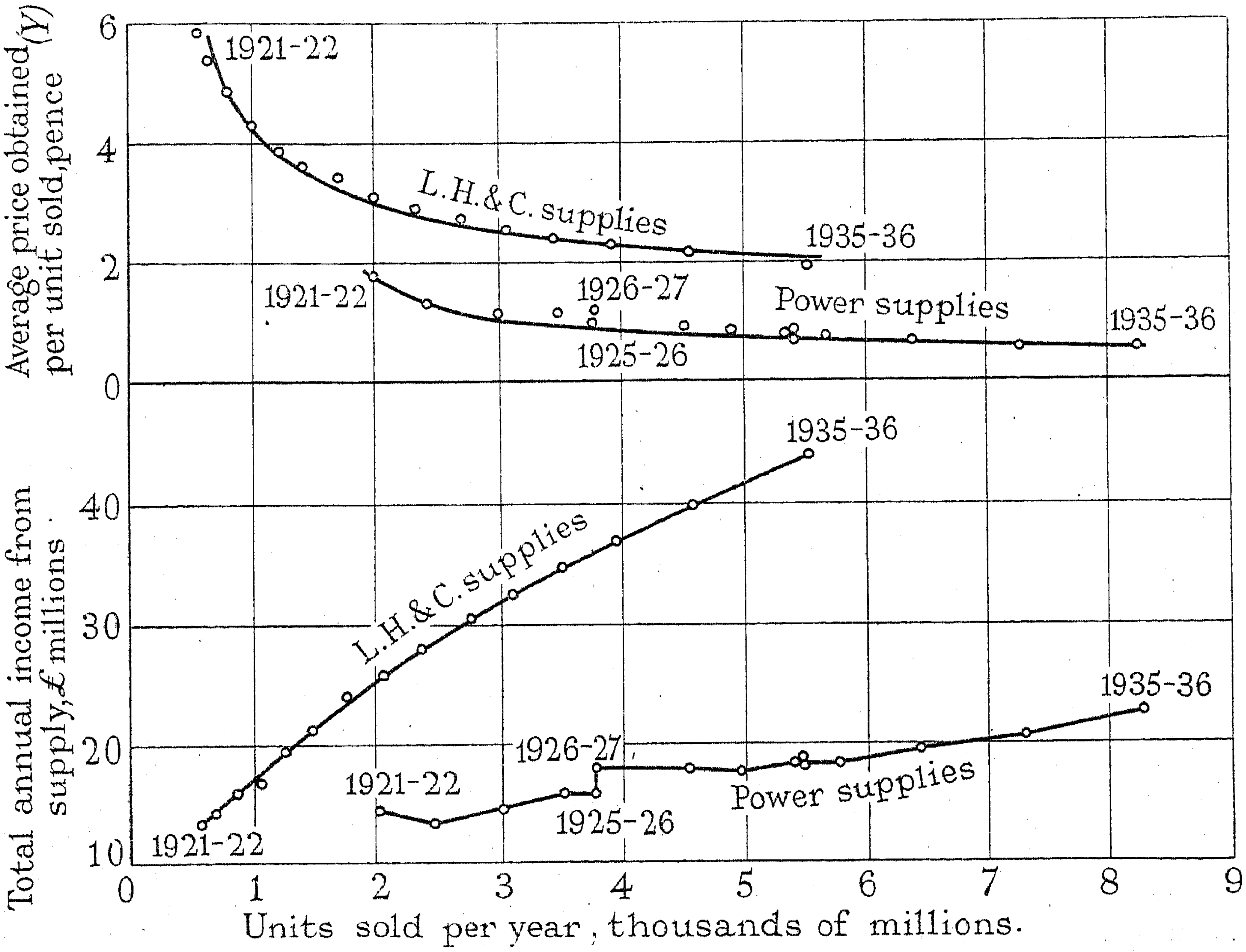

Fig. E.—Relation between sales (kWh) and (*a*) Average revenue per kWh sold, (*b*) Annual income (£).
Equations to curves:—

$$\text{Lighting, heating, and cooking: } Y = 1\cdot 63 + \frac{2\cdot 675 \times 10^9}{\text{Total units sold}} \qquad \text{Power: } Y = 0\cdot 25 + \frac{2\cdot 82 \times 10^9}{\text{Total units sold}}$$

Total revenue from lighting, heating, and cooking supplies

$$\propto 1\cdot 6 \times \text{units sold} + 2\cdot 67$$

Total revenue from power supplies

$$\propto 0\cdot 26 \times \text{units sold} + 2\cdot 6$$

The greater elasticity in lighting, heating, and cooking supplies may be observed by assuming integer values, of say 1 to 10, for the units sold and then observing the manner in which the resulting values of total revenue increase in proportion to the increase in units sold, for each class of supply. The high value of elasticity in the sales of lighting, heating, and cooking supplies is likely to persist for several more years. The conclusion which I suggest can be drawn from Fig. E is that there seems to be very little to be gained by extending the sales of power supplies, at the present decreasing rate of charge, unless it can be clearly shown that such sales would reduce the general costs by improving the characteristics of the general supply. It is, however, quite clear that, for some time to come, an extension of the sale for domestic supplies will prove highly remunerative even if the average charge per unit is reduced considerably. When it is realized that an increase in the sales of domestic supplies will greatly improve the characteristics of the general supply, it will be seen that a considerable reduction is possible in the charge per unit before the curve of the annual income becomes a flat one.

Units Sold per £ of Distribution Capital

A number of speakers have referred to the factor of "units sold per £ of distribution capital"—a criterion introduced by Mr. Kennedy and Miss Noakes in 1933. I suggest that, when discussing this factor, insufficient attention has been given by contributors to the discussion of the paragraph on pages 447 and 448 headed "Summary of the Relationship between Factors (*a*) and (*b*)." Several speakers suggest that the above criterion is not satisfactory as a measure of efficiency because it does not take account of temporarily unproductive expenditure. If we were considering the case of a single small undertaking, for only a limited period of time, this criticism might be correct, but we cannot assume that conditions are static and final for even the smallest and most unprogressive undertaking.

The expenditure in each recent year by most undertakings of any size is usually a small percentage of the total, and hence its effect will not be so large as many speakers seem to infer, even if we were to assume that the expenditure does not gradually become remunerative, as it does in practice. But I have to agree that there is contained within the criticism the real truth of the position, which appears to be that expenditure in the future is not likely to be so remunerative as expenditure in the past, nor will it become remunerative so quickly as in the past when there was an unworked field of potential supply available for exploitation. Col. 9 of Table 8 (page 443) shows that the percentage return on the total capital invested in the industry has fallen from 23·6 per cent in 1921–22 to 15·5 per cent in 1935–36. As I have pointed out on page 447, the annual return on capital consists of the product of (*a*) the average revenue received per unit sold and (*b*) the units sold per £. The average revenue received per unit has fallen in each year, and must continue to do so if we are to maintain the present rate of sales. It follows, therefore, that the units sold per £ must increase so as to maintain the product of the two factors (*a*) and (*b*). If, as is suggested during the discussions, we can expect the units sold per £ to fall in the future owing to the present and future field of exploitation being less remunerative, then it is obviously necessary to reduce the costs of providing supply for items 2 and 3 in Table 9, i.e. repairs, maintenance, and management. As I have pointed out on page 448, and as is confirmed by contributions to the discussion, we can no longer expect any serious reduction in the cost of generation and we are then forced to the conclusion that it is vital that a reduction in costs must occur in distribution, unless we can increase the units sold per £. I have stated in the paper that we have here the real criterion as to the future position of distribution and that, personally, I consider the position to be more serious than appears to be appreciated in the discussions. Since the paper was written an entirely new and unforeseen position has arisen, owing to the sudden increase in the costs of providing supply. The cost of coal has risen enormously (and probably permanently) and has wiped out in a few months a large part of the savings effected during recent years by increased economy in generation. It is almost certain that the curve of cost of generation (curve D, Fig. 5) will cease to fall, as in previous years, and may actually rise. Therefore, to maintain the same average curve of total cost (curve C, Fig. 5) the cost of distribution (curve E, Fig. 5) will require to fall by an amount corresponding to the increase in the cost of generation. Unfortunately, there is no tendency to fall shown by the distribution cost curve (curve E) even under normal conditions, and we now have to face a rise in price of the cost of the basic materials of distribution, which rise may actually tend to cause the cost curve (E) of distribution to rise also, for at least 1936–37–38 if not for a longer period. Mr. Townley refers to the possible effects of the amalgamation and co-ordination of supply undertakings. I had purposely left this factor out of consideration when writing the paper, as being a matter which was then *sub judice*, but if my contention is correct as to the somewhat critical position which has now been reached in the supply industry, the question of the amalgamation of supply undertakings should receive the most careful and impartial attention of all those who are desirous of increasing the efficiency of the electricity supply industry. If by a scheme of amalgamation the costs of distribution can be decreased, and if the amalgamation will result in a greater unification of tariffs and thereby lead to an increased rate of consumption, it would seem that a rejection of the scheme of amalgamation will react seriously on the future, and somewhat critical, position of the supply industry.

REPLY TO LONDON DISCUSSION

I have dealt in my general reply with most of the points arising from Mr. Beauchamp's contribution to the discussion, but I would point out that to the manufacturer the cost of power is only a very small proportion of the total cost of production. In my opinion, increased prosperity in industry must be sought in other and more fruitful directions than the reduction of power charges. I have no objection to our subsidizing industry by giving unduly low power charges (and there is probably a sound economic reason justifying such a course), provided that the subsidy to the power consumer does not take place at the expense of the domestic consumer. When the domestic load is developed fully by the use of a standard tariff with a low running charge, I think that it will be quite possible to continue the annual reduction in power charges at more than the present rate.

The data which Mr. Townley has so kindly given for the West Ham undertaking are very interesting. They show that the increase in the number of consumers had the effect of reducing the average consumption. But, to appraise the position more completely, I think that Mr. Townley should have given details of the reduction in charges that have been effected during the period under review (1925–37), because 1934–37, which is the period during which the average consumption began to increase again, coincides with the introduction of a domestic secondary charge of ½d. per unit and a night water-heating rate of ⅓d. per unit. I give below in Table H the various data which Mr. Townley has been so good as to provide with his contribution, with details of tariff reductions and alterations in charges. In view of comments made during the discussion I hesitate to draw any conclusions from this Table and must content myself with pointing out that the increase in average consumption at West Ham commences from the time when a new tariff of a less restrictive nature was brought into operation and when a domestic secondary charge of ½d. per unit came into use. The Table also appears to give some indication that the elasticity of demand becomes a maximum when the charge per unit becomes ½d. I think that the Table should modify Mr. Townley's view that an increase in domestic consumption will not follow automatically on a reduction in charge.

Mr. Sayer's contribution to the discussion is greatly appreciated, but the general reply which I have given touches most of the points which he raises.

In reply to Mr. Bolton, I would confirm my belief that an increase in the number of domestic consumers will automatically lower the average fixed costs per consumer. This is not a question of diversity but of the greater contribution towards the fixed annual charges of providing the system, which charges continue almost independently of the number of consumers. I do not, therefore, agree with the deductions which Mr. Bolton has made in respect of Table 13 *et seq.* As regards Table 2, I would point out that, however the field may be subdivided, the same curve will always be obtained. As regards the " incremental price," I cannot quite understand in what manner Mr. Bolton intends this term to be used. The price which a person is willing to pay is, of course, the incremental unit's price, but I have yet to find that any economist has been able to show how this value may be determined in terms of real cost. Surely, when we are dealing, not with one consumer, but with a mass of consumers, we must take the *mean* price per unit as the incremental price per unit, otherwise consumption would not stand at that figure.

I suggest that Mr. Hooper is not correct when he says that I have referred to the " disadvantage of the power load." What I have tried to show is that the developed domestic load has better characteristics than the power load and should therefore be encouraged by the offer of charges comparable with those offered to power consumers.

The distinction which Mr. Bernard makes between a commodity and a service is really a very fine one. One definition of a commodity is " a convenience, or that which affords it," and I think that this definition adequately connotes what both Mr. Bernard and I have in mind when considering electricity supply. I agree that the elasticity of demand is dependent upon other factors than those to which I have referred in the paper, but I consider that we are at too early a stage in domestic supply for the other considerations which Mr. Bernard mentions to be of much effect.

Table H

DATA FOR WEST HAM UNDERTAKING, 1926–1937

Year	Units per £	Average domestic consumption, kWh	Domestic tariff
1926	113	319	Introduction of domestic tariff based on lamp wattage Basic charge 8s. per 1st lamp + 1d. per unit
1928	—	—	Basic charge reduced to 7s. per lamp Secondary charge reduced to ¾d. per unit
1929	—	—	Basic charge reduced to 6s. per lamp
1934	68*	286	Room basis substituted for lamp basis Secondary charge reduced to ⅝d. per unit
1936	85	—	Secondary charge reduced to ½d. per unit
1937	90	456	Domestic night water-heating rate introduced at ⅓d. per unit

*1932 figure.

I agree with Mr. Melling's statement as to the method of determining when a particular load is remunerative, but the difficulty that I foresee in applying the criterion is in obtaining a satisfactory method of determining the incremental costs incurred, as I think is shown by the example which he quotes. Accountancy methods of determining costs are not always satisfactory because they tend to restrict the investigation to the particular case as it exists at the time of examination, without full consideration of the wider issue and more general case which is so often involved. I also agree (see my reply to Mr. Bolton) that all additional consumers and loads assist to reduce charges by their contribution to overhead expenses. But until the incremental costs can be determined satisfactorily there is a danger that we should consider that the transaction is bound to show a profit if only a sufficiently large number of units are sold, even though there is a small loss incurred on each unit sold.

In reply to Mr. Patmore, I would confirm that the distribution costs which are shown in the paper include the cost of sales and development work. The type of tariff which Mr. Patmore suggests, i.e. one which is based on some simple form of annual service charge and will include the use of as much energy as a consumer requires, is, I think, one which the supply industry will have to adopt ultimately if all domestic consumers are to reach the " high " stage of consumption which I have envisaged in the paper and which relates to at least 2 000 units average consumption per domestic consumer instead of the 400 units which now applies. This tariff is on the lines of one suggested by Mr. Klitz during the Belfast discussion, where he referred to a " kilowatt-year " era of consumption.

The data which Mr. Harrap has compiled are valuable and illustrate the point which he raises, i.e. that further analysis of the progress of domestic electrification is very necessary. I would also endorse Mr. Harrap's view that it is desirable to find whether there is a pronounced relationship between capital expenditure on hired appliances and the subsequent increase in output.

I am afraid that I cannot accept the suggestion made by Mr. Pass, that because Table 1 shows a gradual decrease in average domestic consumption from 1927, the value of average domestic consumption is not a true criterion of progress. I agree, of course, that there must have been an increase in the consumption of many consumers who have been connected since 1927, and that this increase has maintained the average at about the same level. But are we to be satisfied with an increase of this nature? If we assume that each consumer should normally increase his consumption so as to use 2 000 units per year after 5 years, the total consumption for 1934–35 should have been achieved by the consumers who were connected at 1930–31, if no other consumers had been connected. With Mr. Pass's remarks on hired apparatus I fully concur.

I think that Mr. Rowson makes the mistake of assuming that conditions in a supply undertaking ultimately become static and final. His argument, as I understand it, is that the sales of electricity for an undertaking are subject to increasing returns until the maximum load has been reached on the initial system of cables or lines, but that the additional cables or lines laid subsequently are not subject to increasing returns. The mathematical proof which Mr. Rowson provides is very interesting but it does not contain all the factors required to demonstrate the case which it is desired to prove. We are really considering the rate of change of *total cost of providing supply* with the increase in load and not simply the rate of change of cost of cable, as is assumed in Mr. Rowson's demonstration. It is also assumed in his expression that the cable is always fully loaded, which is not the case in practice. I am not clear as to why the constant d should be regarded as a charge per consumer, in an expression which is indicative of the cost per unit length of cable, particularly since Mr. Rowson states that this constant decreases at first, as more consumers are connected; it is agreed, however, that there is an annual charge per consumer which is quite independent of his consumption, but is dependent on the number of consumers. In general, I am of the opinion that Mr. Rowson's more general proof fails because he does not prove that *all* the charges on the system vary with the units sold. Referring to the revenue per kW of maximum demand, Mr. Rowson has not allowed for the enormous increase in diversity which would ensue if there was a radical increase of domestic consumption, and I fail to see why he applies the same annual load factor of approximately 27 per cent to supplies at ½d. per unit as to supplies at 1d. per unit. It is not quite fair to assume that the group system load factors of Table 4 and the costs of Table 19 would apply to supplies sold at ½d. per unit, and in the subsequent part of the discussion Mr. Rowson ignores the fact that an annual fixed charge would be obtained from each consumer in addition to the running cost of ½d. per unit. The fact that the small undertakings have low "consumer charges" (as defined in Tables 15 and 16) could be due to some of these undertakings having ceased to develop and extend progressively after their initial mains system had become fully loaded, and if such cases do occur the tendency would be toward a low fixed consumer charge and high secondary costs per unit. The low fixed charge is not, therefore, necessarily a measure of efficiency, as Mr. Rowson would suggest.

REPLY TO BIRMINGHAM DISCUSSION

Mr. Allen states that it is wrong and often dangerous to use average results of the past in order to determine policies and conditions to regulate the future. But I would ask how otherwise are we to obtain guidance for the future? Mr. Allen joins with Mr. Townley in stating that I should have limited the analysis to those undertakings which are the most efficient, but I suggest that the results would then have been less valuable and would lead to false conclusions when considering the position from a national viewpoint. I am also afraid that I should have been accused of being invidious in my choice of undertakings even if there were an agreed criterion by means of which it could be determined which are the efficient undertakings. I cannot agree that, if each supply authority were left to determine the amount of fixed charge, there would then be no standard tariff, and I would refer Mr. Allen to the definitions of the word "tariff" which I have given on page 448. If, for example, all undertakings agreed to charge consumers on a two-part tariff with each consumer's fixed charge based upon, say, his rateable value, I maintain that this would comprise a standard tariff or basis of charge, within the terms of my definition, even though the amount of the fixed charge varied with each consumer. The "consumer charge" form of tariff which is suggested in the paper would involve different fixed charges for each consumer at the outset, but there would be a much greater possibility of achieving ultimately a uniform fixed charge for all consumers than is likely to occur with any form of tariff now in use. I do not see that it would be contrary to general business principles if prosperous undertakings were called upon to subsidize less prosperous ones. This principle of subsidizing is adopted, of necessity, by all progressive business undertakings. For many years, and until the charge for telegrams was reduced, the G.P.O. telegraphs were subsidized by telephones and postage rates, and to-day the short-distance telephone trunk calls at 1s. pay for the long distance calls at 1s., with great success, just as letters weighing 1 oz. and delivered locally at a charge of 1½d. pay for those delivered overseas at the same charge. With the remaining part of Mr. Allen's contribution I am in very full agreement, except where he maintains that standardization of tariffs is a need which is secondary to commercial development. In my own view the standardization of domestic tariffs must be brought about before commercial development can become effective.

Mr. Hooper suggests that the total natural growth of sales in units can be accepted as a measure of progress, but with this I cannot agree because the factor of cost is not brought into the equation. In any case, one would naturally expect that an industry such as electricity supply which is yet in its infancy would grow rapidly, in the same manner as an infant or adolescent child. I have already indicated, in the general reply, that I consider that power charges are derived upon a competitive, rather than a cost, basis, and I think that this view is implied in Mr. Hooper's remarks with regard to Diesel engines. I do not see the harm in classifying small with large undertakings if the totals for the smaller undertakings hardly make any difference.

I think Mr. Joseph's use of the term "false conclusions" is somewhat ambiguous, but I would point out that his extrapolation of the curve in Fig. 3 is continued to a much greater degree than I have attempted when deriving my conclusions. Most of the other points of Mr. Joseph's contribution have been dealt with in my general reply and I am in general agreement with them; also I gather that he supports me to some extent in my suggestion of a "fixed consumer charge." I agree with his suggestion that this charge would have to be varied to suit varying classes of consumers, but he will see from my general reply that I do not suggest that the fixed consumer charge should be standardized at £5; this was the theoretical value arrived at in the paper.

I agree with Mr. Mair, in the balanced comments which he makes, that it is lamentable that there are not available to the electricity supply industry a complete set of statistics; this lack of statistics compels assumptions being made in any study of the industry. Wherever it has been possible, I have referred to sources of information additional to the Financial Reports of the Electricity Commissioners, but, in general, except for the tables of costs which the *Electrical Times* has published for many years, there are very few data available relating to electricity supply. As regards the assumptions which I have had to make as to the number of domestic consumers in each year it is interesting to note the following comparison. The Electrical Development Association has recently published figures of total domestic consumers which are taken from the only published information on the subject. This is contained in the "Electrical and Radio Trades Market Survey of Wired Homes," published by *The Broadcaster and Electrical Trading* (Odham's Press). These figures are shown in Table J beside the data as to the estimated number of domestic consumers which are shown in Table 1.

Table J

Year	Estimated domestic consumers	
	Table 1 (page 430)	E.D.A. Diary, 1937
1930–31	3 300 000	
1931–32	3 930 000	4 309 729
1932–33	4 620 000	4 882 181
1933–34	5 270 000	5 392 800
1934–35	5 980 000	6 073 706
1935–36	6 600 000	6 598 043

As regards system load factor, I would point out that I have stated that the *fully developed* domestic load will be likely to provide a system load factor equal to, or greater than, the *developed* industrial load; Table 5 does not purport to show the effect of a *fully developed* domestic load. I consider that the power load to-day is in a fairly advanced state of development and that any additional power load that may be obtained may tend to reduce the average load factor. Conversely, I maintain that the domestic load is grossly under-developed and that we have obtained as yet only the minimum load, at its lowest load factor. I think that this fact is implied in the brief analysis made by Mr. Mair at the end of the second paragraph of his remarks. As I point out in my general reply, the average factory working a 48-hour week (which in normal times comprises the bulk of the power load available) has an annual load factor which is usually less than 20 per cent, whereas even a small lighting consumer will very often have an annual load factor equal to the above figure. I cannot therefore agree that my assumption of equal system load factor for domestic and industrial supplies is unsound, nor that the conclusion which follows, but does not depend upon, this assumption is incorrect and in support of this I would refer Mr. Mair to the effect of the domestic load in improving the load factor at Hull, as shown in Mr. Waite's contribution to the Leeds discussion. In general, however, I endorse very fully the comments made by Mr. Mair, who seems to appreciate the difficulty of making an analysis of the nature of that in the paper, without bringing in certain assumptions; I join in his regret that statistics are not available which would obviate the need for many of the assumptions.

I appreciate also Mr. Elliott's contribution to the discussion. It is refreshing to find a candid approval of the fact that the average annual consumption per domestic consumer is decreasing and, from the fact that the Wolverhampton undertaking approaches a figure of 700 units average consumption, for lighting, heating, and cooking, despite the increase in small consumers, it would appear that the sales to the larger domestic consumers are being well maintained. This is evidenced by the fact that the Wolverhampton undertaking could apply to each of its domestic consumers an averaged annual consumer charge as low as £3, despite a progressive increase in mains development. I am not clear, however, whether the 3 per cent of the total fixed charges which Mr. Elliott mentions as relating to the total expenditure for power consumers includes a proportion of cost for those h.t. mains which supply both l.t. and h.t. demands, and on what basis the allocation of 3 per cent is made.

I agree with Mr. Blaikie that it is the average consumption of the consumer and not the overall size of the undertaking that is the dominating factor in the price charged per unit. An indication of this may be observed in Table 2, cols. 9 and 10, where it will be seen that the increase in average annual consumption (col. 9) is not progressive throughout the whole range of groups of undertakings. As I have mentioned in the paper, there is a possibility that the best results are obtained when the annual output of the undertaking is somewhere between approximately 25 and 50 million units. To substantiate this suggestion would, however, require more data than I have available. With Mr. Blaikie's remarks on load factor I am largely in agreement.

REPLY TO LEEDS DISCUSSION

Mr. Waite's contribution is of interest and value if only because of the data relating to the special matters dealt with in the paper which he has made available. I do not see that his Table A contradicts my conclusions, but rather that it proves them. The Table shows that in the city area Mr. Waite is charging an average price of 1·88d. per unit and selling only 14·8 units per £ of distribution capital, whereas in the outside area he is charging only one-half this price, i.e. 0·9d. per unit, and selling, presumably as a consequence of this lower price, 24·4 units per £, or nearly twice the amount per £ of distribution capital; it will be noticed that the annual return on capital is 11·6 per cent in the city area and 9·2 per cent in the outside area. The annual return on capital is not, by itself, an adequate criterion of efficiency, but Mr. Waite's statement that the outside supply is bringing in sufficient revenue to cover all the costs of giving that particular supply seems to confirm the view which I have put forward consistently (see also page 449, par. 2) that a rural undertaking can work satisfactorily with a lower annual return on capital than an urban undertaking. I am very glad to have the authoritative confirmation of Mr. Waite that a policy of low prices and large sales yields the best financial results and also that a decrease in price must precede an increase in demand. I am also pleased to note that Mr. Waite puts forward low flat rates as one of the reasons for lack of development in domestic consumption, although I would point out that I have mentioned this point in the paper and that I go so far as to suggest that domestic flat rates should be entirely abolished. As regards the question of guarantees, I can only put forward for consideration the success of the Dumfries undertaking, which has never imposed guarantees or service charges. It is not clear to me why Mr. Waite (and several other speakers) should maintain that I have discriminated and particularized against the small undertakings. The analysis in the paper was made by considering electricity supply for the country as a whole, but it was not possible to avoid the conclusion, made on page 434, that 72 per cent of the total number of undertakings have only 20 per cent of the total domestic consumers; also that the average annual domestic consumption of 378 units for these 72 per cent of undertakings is less than half that of the remaining 28 per cent of undertakings. But I also maintain that the average domestic consumption remains stationary for the whole country and I agree with Mr. Waite that this implies a much stronger case against the remaining few but larger undertakings, which are mainly responsible for determining the average figure for the whole country. I had rather gathered from the discussions at other Centres that this was understood to be my case. I am pleased to have Mr. Waite's agreement to certain other views put forward in the paper, and I have dealt in my general reply with most of the remaining points of his contribution. May I say, however, that I do not put forward the view, as Mr. Waite would imply, that the offer of a follow-on rate of ½d. per unit is in itself likely to increase consumption, nor am I of the view that the offer of any particular kind of tariff will automatically achieve this end. What I do wish to stress is that we require uniformity for all undertakings in the method of determining the consumers' fixed charge and in the follow-on rate per unit, so as to remove suspicion and bewilderment from the minds of consumers and laymen; I have dealt in the paper with the monetary amounts of these two qualitities only to show that uniformity would not be likely to disturb the income from supply and involve any serious departure from the present position.

I would put forward the statement made above in reply to the argument which is contained in the first paragraph of Mr. Crowther's contribution. I was very interested in the detailed case which he has put forward because it illustrates the argument which I have adduced in the general reply, i.e. that it is difficult, or impossible, to ascertain the true cost of providing supply, also that if this cost were available we should not strictly charge the consumer on this basis. I give in Table K the cost per unit at various consumptions which result from the two-part costs derived by Mr. Crowther.

Table K

Location of supply	Cost of supply with group system load factor of 30 per cent	Annual consumption, kWh					
		100	1 000	2 000	5 000	10 000	20 000
		Costs per kWh (pence)					
Town	£2 per consumer + 0·71d. per unit	5·51	1·79	0·95	0·81	0·76	0·73
Country	£4 per consumer + 1·25d. per unit	10·85	2·21	1·73	1·45	1·35	1·30

Is it proposed that the consumer supplied from the country substation, who may live near to a consumer supplied from the town system, should be asked to pay 1·30d. per unit for an estimated annual consumption assumed at 20 000 units, or 10·85d. per unit for an annual consumption of 100 units when the town consumer is paying only half these prices? I suggest, in the first place, that the whole range of prices which result to the rural consumer by the application of a strict costing basis are uncommercial and impracticable, more particularly in the case of the larger annual consumptions. I suggest also that the great difference in the charge per unit which would have to be made to the town and country dweller respectively if strict costing methods were used to determine charges would result in suspicion of the supply authority and a bewilderment which would not be dispelled by the most efficient sales organization. The course which would be followed in practice would be to charge the rural consumer, quite arbitrarily, an additional 10 or 20 per cent so as to cover the alleged higher costs of distribution in the rural area.

methods are required, but, as I have pointed out, the final decision as to the nature of the tariff and the amount charged will require to be considered from an arbitrary rather than a scientific standpoint. In reply to Mr. Cooper's references to Table 13, I would refer him to the curves which I have published in my general reply and to the values of the equations derived from those curves.

In reply to Mr. Orchard, I agree that domestic consumers with a low annual consumption will eventually increase their consumption. It is questionable, however, whether this increase will be of such a magnitude, and will have a rate of increase sufficient to match the decrease which is required each year in the cost of providing supply.

Mr. Royle suggests that the data of finances and consumption which are issued by the Electricity Commissioners are not correct and are not accepted by the electricity supply industry. I did not know that this was so and it would appear to support even more strongly the views of Mr. Mair and myself as to the lamentable inadequacy of statistics relating to the industry. Mr. Royle points out that the average figures which I have shown in Table 1 are higher than the true average for domestic consumption only, and with this I agree. This, I think, is the answer to Mr. Royle's question as to why the domestic consumption at Darlington and Sunderland fall well below the figure which I have given. In reply to Mr. Royle's further question, I would remind him that certain of the undertakings shown in the Electricity Commissioners' Returns are selling a major proportion of their supplies in bulk and these undertakings have been omitted from the analysis because the inclusion of their sales would have produced a very misleading picture for domestic supplies. Mr. Royle's Table E is very interesting and the data in the last five columns seem to confirm the curve shown in Fig. 3 and the arguments which I have deduced from that curve. Table 5 was not introduced to show that the undertakings numbered 1 to 6 were more progressive than the undertakings numbered 7 to 12, but to show that the system load factor for an undertaking with a reasonably developed domestic load may equal the load factor of the power load. The conclusions which Mr. Royle draws from Table 5 are not, therefore, correct ones. Referring to his last paragraph, a power consumer with an annual load factor of 60 per cent is entitled to a relatively lower price per unit, whether his consumption is large or small, but I should imagine that this class of consumer occurs less frequently than Mr. Royle would suggest.

I thank Mr. Lennox for his contribution and general agreement, and I have dealt with most of his points in my general reply. The difficulty of the collection of money with a uniform two-part tariff could probably be met by obtaining the quarterly or half-yearly fixed charge in advance. I agree fully as to the need for a unified system of costing. I should like to endorse Mr. Royle's suggestion that more consideration should be given to the use of the all-in charge collected weekly.

I am also obliged to Mr. Oswald for his interesting cost analysis for various classes of consumer. I note, however, that the cost per unit to the domestic consumer with a large consumption is low (0·76d. per unit) and that it would not be appreciably less for the normal type of power consumer. The power consumer quoted in the last line of Table G is comparatively rare and is largely an " off-peak " consumer; if the 700 kW were taken at peak-load time the cost per unit would work out at 0·68d. per unit, at the price, quoted earlier, of £4·95 per kW + 0·262d. per unit.

THE EXAMINATION AND RECORDING OF THE HUMAN ELECTROCARDIOGRAM BY MEANS OF THE CATHODE-RAY OSCILLOGRAPH

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SUMMARY

The cathode-ray oscillograph, having no inherent inertia and yet being comparatively indestructible, is an instrument peculiarly suitable for everyday electrocardiography. A fluorescent screen of very long afterglow enables the electrocardiogram to be examined directly at the patient's bedside, which is a new facility.

The design of the amplifier has to be adapted to the peculiarities of the heart-action voltages and electrical constants of the patient; these are considered in some detail, and practical methods for the examination of the adequacy of the amplifier are discussed.

The provision of a high-voltage supply suitable for any eventuality is considered, together with methods of obviating interference, especially from alternating-current mains.

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(1) INTRODUCTION

Activity, in all living tissue, is associated with an electrical change. The active part of the tissue acquires a negative potential with respect to the inactive part, and, in an outside circuit, current will tend to flow from the inactive portion to the active, if suitable electrodes are applied. For example, during the passage of a nervous impulse along a nerve, the part of the nerve where the impulse is momentarily present, is, during that short time, negative in potential with respect to the inactive part. Similarly, activity in muscle is associated with quite large (up to 20 millivolts and more) changes of potential. In the case of the heart, which is essentially no more than a mass of specialized muscular tissue, so arranged that it acts as a pump, the activity is rhythmic. There is, accordingly, a corresponding rhythmic and regularly-recurring wave of potential difference between any two points on the surface of the heart. The wave-form is complex; its period is very long, corresponding, of course, to the pulse rate; this is very variable, but is commonly about 70 beats per minute. It is a fair presumption, therefore, that electrodes connected to the limbs of a patient (Fig. 1) will show rhythmic differences of potential, corresponding to the activity of the beating heart within the patient's body. Most of the potential difference between the two areas of the heart's surface will disappear by reason of the good conductivity of the tissues surrounding the heart, especially the pericardial fluid; nevertheless, there is quite usually a p.d. of more than a millivolt, at the short time where it is maximum [the "R" peak of the electrocardiogram shown in Fig. 2 (see Plate 1, facing page 508)], between electrodes applied to the hands or arms of the patient.

Although Kölliker and Muller, in 1855, had demonstrated by physiological experiment that an electrical change accompanies the beat of the isolated frog's heart, it was Waller who first showed, in 1887, that it is possible to demonstrate an electrical change occurring in the human heart when electrodes are applied to the limbs. The instrument he used for this purpose was the capillary electrometer, of Lippmann. His experiments remained, however, of physiological interest only, and it was not until the invention of the string galvanometer by Einthoven (in 1903) that the science of electrocardiography, as we now know it, was fairly launched in the world of medicine. Einthoven's invention and his subsequent work completely altered the whole outlook of cardiologists throughout the world, and the significance of this new branch of medical science was quickly grasped by many practising physicians.

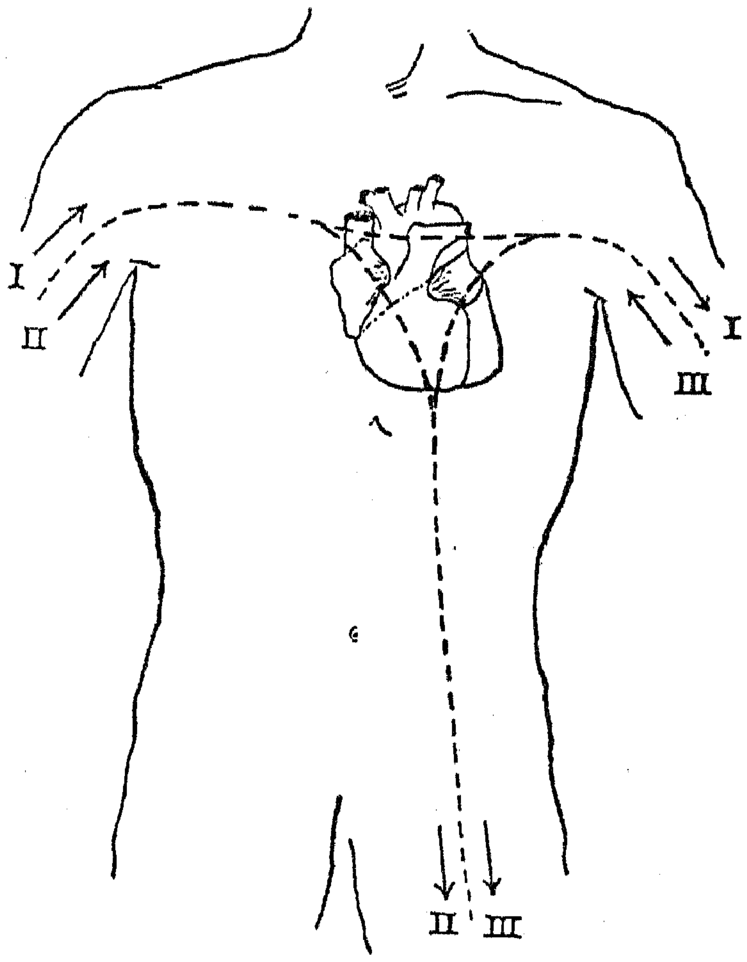

Fig. 1.—Diagrammatic representation of the three classical leads of Einthoven.

Following Einthoven, certain standards are universally adopted for electrocardiographic work. The three standard connections to the patient, or "leads," are as follows (see Fig. 1 and Fig. 21A, Plate 4, facing page 509).

Lead I.—The electrocardiograph is connected between leads taken from the right and left arms of the patient. The resulting electrocardiogram gives, therefore, a picture of voltages appearing across the base of the heart.

Lead II.—Connection is made between the right arm and left leg of the patient. The record is therefore one of voltages produced between the base and apex of the heart; accordingly, since the heart is tilted on its side within the chest, Lead II gives a composite electrical heart picture.

Lead III.—Between the left arm and left leg; this lead therefore records electrical events occurring chiefly in the left ventricle.

It will be appreciated that the three standard leads of Einthoven record electrical events, happening within the heart, in one plane of space only—what is known anatomically as the coronal plane. In recent years, following American practice, cardiologists have been using a fourth lead, where one electrode is placed on the front of the chest at the apex of the heart, and the other on the patient's back (at the angle of the left scapula). The resulting picture shows potentials in an antero-posterior plane. In practice this fourth lead does not give a great deal of additional information about the condition of the heart, except in certain cases of coronary infarction. And, although it must be agreed that Einthoven's three standard leads are not perfect from the standpoint of physics, they are at least anatomically satisfactory and have the great advantage of easy practical application; nor is there any possibility of different positioning of the electrodes (with respect to the heart) at successive examinations.

Einthoven's standard of voltage calibration is that 1 cm. of movement of the magnified image of the string represents a p.d. of 1 millivolt between its ends. In electrocardiographic practice this determines a convenient height of curve, and, as there are few cases where the movement of the string is greater than 3 cm., the width of the record is not unreasonably great. Einthoven did not, however, establish any standard for the time abscissa. Most electrocardiographic records have been taken hitherto at approximately 1 in. (2·54 cm.) per sec., but a time marking is always indicated on the record, usually in the form of vertical lines ruled at each fifth of a second. Where the pulse rate is rapid, the speed of the recording plate, or film, is commonly increased, in order to produce a clearer record. It seems a pity that Einthoven did not fix such a standard, for it is now common practice among electrocardiographers to describe, and make deductions from, the actual shape of the waves of the electrocardiogram;* and, that being so, it would appear essential that there should be as much a standard for the abscissa as for the ordinate of the curve. If such a standard becomes uniformly adopted it must surely be in the same units as the standard for voltage calibration; it is suggested that a film speed of 2 cm. per sec. may be found suitable. Most of the cathode-ray electrocardiograms shown conform to these standards, namely, a voltage calibration of 1 cm. per millivolt, and a film speed of 2 cm. per sec.

Since the introduction of the original string galvanometer many other types of electrocardiograph have been made. Each one of these has been an endeavour to produce an instrument which is more portable and more robust than the string galvanometer. At the same time, during recent years, the string galvanometer itself has been greatly improved in both these respects. Nearly every one of these instruments uses some form of mirror galvanometer, of comparatively low sensitivity, in conjunction with an amplifier embodying thermionic valves. Unfortunately some of these instruments have been constructed with valve amplifying circuits which were by no means free from distortion, so that the term "valve electrocardiograph" has (quite unjustifiably) tended to become a byword in cardiology. It will be readily appreciated that the design of the amplifier for use in electrocardiographs employing any indirect recording system is an extremely important matter, and it will be discussed in some detail hereafter, in its application to the cathode-ray oscillograph.

The first workers to use the cathode-ray tube in bio-electrical work were Gasser and Erlanger, in their work on the action potentials of nerves. At the present time, many workers in bio-electrical fields, realizing its unique properties, are adapting the cathode-ray tube to their own particular problems; a general account will be found in Holzer's book.* Among the first to adapt it to electrocardiographic work was Rijlant, of Brussels (1931, *et seq.*), who has published many papers on the subject. Schmitz,† in Germany, and Matthews (1933),‡ in this country, were also among the first to publish electrocardiograms recorded by the cathode-ray oscillograph (C.R.O.). Matthews (1934) was able to show that Rijlant's electrocardiograms were inaccurate, and to point out that the new waves (P_2, T_2, etc.) described§ by him were really caused by deficiencies in his amplifier. But each one of these workers had merely used the cathode-ray tube, in conjunction with an amplifier, essentially in exactly the same way as the string galvanometer—the vertical excursions of the cathode-ray spot corresponding to the movements of the string shadow. Moreover, in no case was the apparatus in any sense portable, far less, in fact, than any of the electrocardiographs already available (e.g. portable string-galvanometer and mirror-galvanometer electrocardiographs, such as those manufactured by Victor, Siemens, etc.). It appeared to the present author that in the cathode-ray tube there existed possibilities for a reliable portable electrocardiograph far ahead of any so far available. Chief among its intrinsic merits is that of virtual indestructibility, as compared with most of the electromechanical recording instruments; for example, it is not difficult, by even momentary careless handling, to break the fine quartz fibre which is the "string" of the string galvanometer. Further, the total absence of inertia of the C.R.O. puts it in a class by itself among recording instruments. Moreover, with a fluorescent screen of long afterglow it seemed likely that it would not be a difficult matter to arrange for immediate visual observation of the electrocardiogram directly at the patient's bedside, by exploiting another of the cathode-ray tube's unique merits—the fact that the cathode-ray spot has two degrees of freedom—so that the application of a horizontal linear time-base would show the electrocardiogram directly on the screen.

In early 1933, when work was begun, two essential factors made for success. The first was that the cathode-ray tube, largely owing to the work of Bedford, was then being produced by Messrs. A. C. Cossor as a reliable and comparatively cheap commercial article; and the second was that materials for fluorescent screens of long afterglow were just being discovered by Levy and his co-workers. Given these essentials, which are discussed in more detail hereunder, the main problem to be worked out was therefore that of amplifier design. It was also necessary to arrange for an efficient, yet portable, H.T. supply adapted to suit all circumstances, so that the electrocardiograph might be worked anywhere: in a hospital or in a country cottage. Some description of the early model of cathode-ray electrocardiograph produced by Bedford and the author is given in a paper published in 1934.[*] Another cathode-ray electrocardiograph was designed by Brookes-Smith,[†] using a cathode-ray tube with a screen having long afterglow, but without any device to obviate origin distortion [see Section (3. 3)].[‡] Other cathode-ray electrocardiographs have also been described, e.g. that of Nielsen.[§]

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* See References, (18) and others.

* See Reference (6). † *Ibid.*, (24). ‡ *Ibid.*, (11). § *Ibid.*, (21).

(2) THE "PATIENT CIRCUIT"

Before passing to a consideration of the design of the cathode-ray electrocardiograph it will be helpful to consider briefly the nature of the "signal" which the apparatus is required to depict, and to examine any incidental electrical phenomena present in the patient himself that may affect it.

Fig. 2 (Plate 1) is a string galvanometer record of an average normal Lead II; that is to say, with the (non-polarizable)[||] electrodes applied to the right arm and left leg of the subject. Time (abscissa) and voltage (ordinate) markings are indicated on it; the curve is read from left to right. Each complete wave-form is a record of the electrical events accompanying each heart beat, and, at the common pulse rate of 72 per minute, occupies, in time, approximately 0·8 sec. Contrary to usual electrical convention, and because biological activity is accompanied by a negative electrical change, movements above the iso-electric baseline are negative, and those below, positive; that is to say, during an upward movement of the string the electrode connected to the right arm of the subject is negative with respect to that connected to the leg. The five peaks, or "waves," of the normal electrocardiogram are designated by the letters, P, Q, R, S, and T. P, R, and T are normally up-going, and therefore negative; Q and S down-going, and therefore positive. This nomenclature, which is now general in electrocardiography, was originated by Einthoven, who sensibly put forward this purely arbitrary scheme of lettering in the absence of sure knowledge of the significance of each peak. All that is definitely known at present is that the P "wave" corresponds to the contractions of the auricles, which are the small collecting chambers of the heart; Q, R, S, and T are electrical events accompanying contraction of the ventricles—the large pumping chambers of the heart.

For purposes of amplifier design the electrocardiogram should be regarded as a complex wave-form of the nature of a random transient, occupying something under 1 sec. in time. A safe assumption will be given by supposing that the electrocardiogram may be represented by a transient of the Heaviside type, but finite in duration. The wave-form and time relations are arbitrarily assumed to be those of Fig. 3. Apparatus designed to give small distortion of this wave-form will be unlikely to give any distortion of the electrocardiogram, because although this occupies more time the wave-form is less strictly abrupt than that of Fig. 3. This matter is considered in some detail in Section (7), where it is hoped to prove that the author's apparatus, as designed, does in fact give a distortionless picture of the electrocardiogram as presented by the particular individual under examination.

Of the incidental electrical phenomena, present in the patient himself, we are concerned with four: resistance, "polarization capacitance" (explained hereunder), skin potentials, and somatic muscle action-potentials. The impedance of the patient, which includes the first two of these, is particularly important.

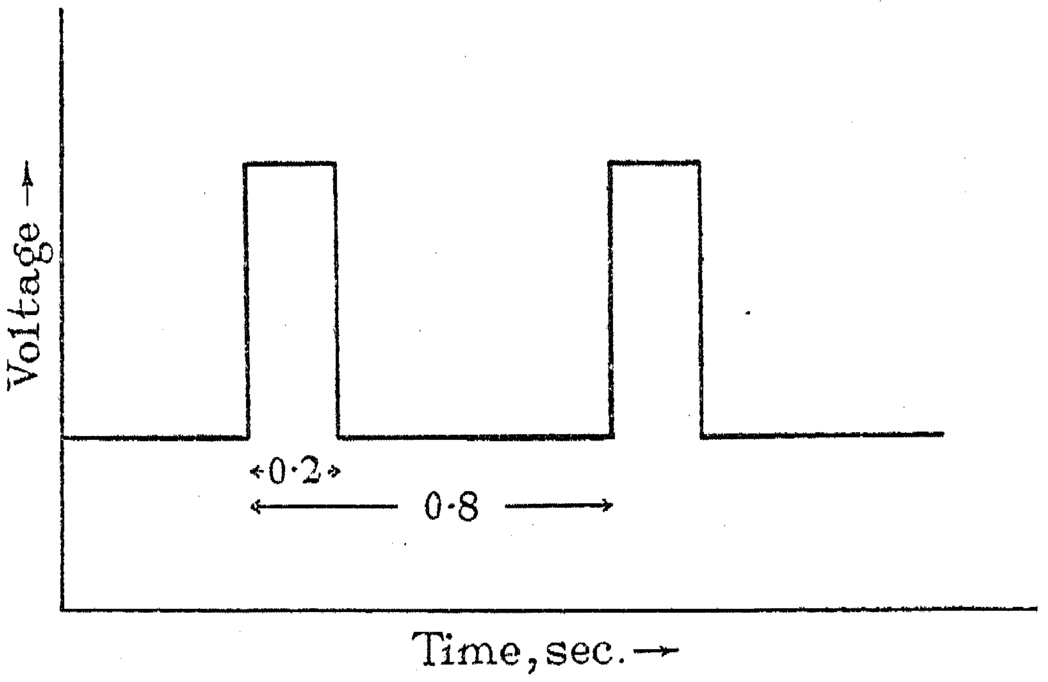

Fig. 3.—Abrupt transient wave-form representing electrocardiogram.

The resistance of the human (or animal) subject from a point beneath the skin to any other point beneath the skin is quite low—a matter of hundreds of ohms only. Nearly all the resistance of the patient is present in the skin itself, and probably mostly in the outermost layer of the epidermis, the *stratum corneum*, which is made of keratin (horn), a good insulating material. Furthermore, there is a large amount of sebaceous matter present in the skin; this is oily in nature, and therefore a poor conductor. If the resistance of the human patient is measured and the connections to him are by non-polarizable electrodes, it will be found that the resistance of the average patient (plus electrodes) is about 2 000 ohms. If non-polarizable electrodes are not used the resistance of the "patient circuit" becomes very much higher, owing to polarization of the electrodes by the current which passes. Even when non-polarizable electrodes are used it will be found that in subjects with particularly dry or oily skins the "patient resistance" may be quite high; moreover, the resistance is initially low but rises quickly and flattens out exponentially.[*] The speed of its rise varies in different subjects, depending on the condition of the skin. If the patient's skin is washed with soap and hot water it will be found that the resistance is now very much lower, and is not so variable. Polarization is, in fact, occurring, not in the electrodes, but at the junction of the skin with the saline, and the skin-electrode junction is behaving like a condenser of quite large capacitance. The passage of current, causing polarization, has created an electrolytic condenser, and the capacitance of this condenser is directly dependent on the current flowing, which is itself dependent upon the resistance of the circuit. The capacitative phenomenon created in this way may be called the "polarization capacitance" of the circuit. Most authors (e.g. Lueg and Gaarz),* assume that these capacitance effects are inherent in the skin itself, but it appears far more reasonable, especially in view of the variability of experimental results, to consider that they are produced at the surface contact between the skin and the electrodes. The matter has been particularly well investigated by Horton and van Ravenswaay,† who used as their electrodes phosphor-bronze wire gauze covered by flannel soaked in 1 per cent saline; but they too do not use any different electrodes or vary the strength of their (very weak) saline, nor do they alter the condition of the subject's skin by cleaning, washing, etc. Fig. 4 gives a schematic representation of the "patient circuit," and summarizes the foregoing remarks.

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[*] See Reference (22).

[†] *Ibid.*, (4).

[‡] Mr. Brookes-Smith is at present working with the author on a redesign of the Cossor–Robertson cardiograph, with the object of increasing its simplicity as a practical clinical instrument.

[§] See Reference (16).

[||] A "non-polarizable electrode" is so constructed that the passage of a direct current through it (in either direction) causes no variation of resistance of the electrode by polarization. The type of non-polarizable electrode commonly used in electrocardiography consists of a zinc rod in a solution of zinc chloride contained in a porous pot which is itself immersed in a solution of sodium chloride of approximate equal molecular concentration; the limb of the subject is then immersed in the saline solution. Readers who are unfamiliar with the subject are referred to an excellent elementary description in "Introduction to Physical Chemistry" by Prof. J. Walker (chaps. 32 and 33).

[*] See Reference (17).

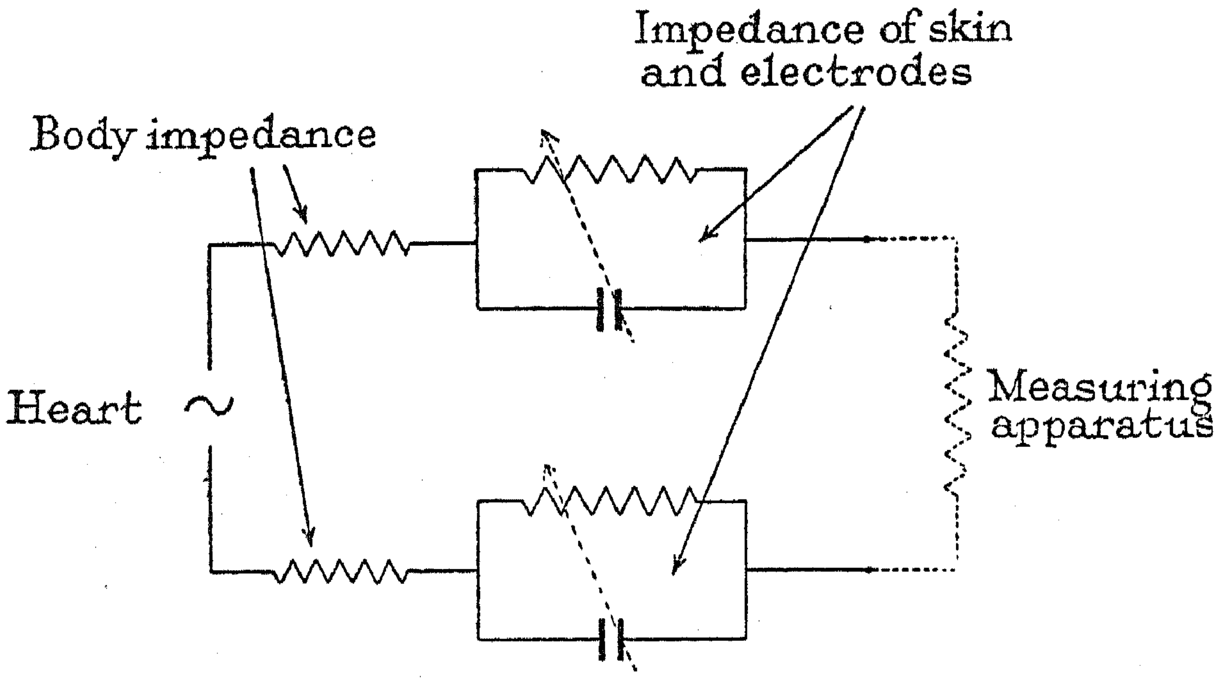

Fig. 4.—Diagrammatic representation of the "patient" circuit.

In practice, the necessary potential difference to cause polarization is created by the skin potentials—loosely called "skin currents." For the most part these are contact potentials developed between the electrodes and the skin of the patient; in part, however, they are potential differences really produced in the skin itself. They are steady maintained potential-differences, and may be very considerable, as much as 50 millivolts, or more. The presence of polarization capacitance causes a distortion of the electrocardiogram which is, in effect, the same as is produced by too short an intercoupling time-constant where a resistance-capacitance-coupled (R.C.C.) amplifier is used [see Section (7)]. In the case of the string galvanometer, where the input impedance (resistance of the string) is in the neighbourhood of 2 000 ohms, the amount of current that passes may be quite considerable, so that if non-polarizable electrodes are not used the distortion which occurs may be quite large. The subject has been discussed by Lewis,‡ Pardee,§ and, in a more recondite manner, by Lueg and Gaarz.* If, as is desirable in a portable electrocardiograph, non-polarizable electrodes are not to be used, as little current as possible should be allowed to pass for the electrocardiogram to give a true picture of the heart action-potentials. The input impedance of the electrocardiograph must therefore be as high as possible, and from this point of view the valve electrocardiograph has considerable advantages, as pointed out by Holzer,† Lueg and Gaarz,‡ and others. But even where the input impedance is high, the use of unsuitable electrodes will still cause distortion, if the impedance between the skin and the electrodes is high enough. This is illustrated in Fig. 5 (Plate 1), where the middle electrocardiogram shows the sort of distortion produced by using metal (german silver) electrodes directly applied to the skin. In practice, small metal-cored cotton-wool pads soaked in strong saline solution will be found of quite low enough resistance to ensure freedom from distortion; it is wise to use a metal which is not easily corroded by saline, such as "Tungum." Alternatively, metal electrodes may be directly applied in combination with "Cambridge electrode jelly."

The matter of somatic muscle action-potentials is of some practical importance, since, if they are excessive, their effect may be such as to obscure almost completely at least the finer details of the electrocardiogram. As a practical measure it is therefore essential for the patient to be at rest, both physically and mentally; he should be warm, comfortably seated or lying down, and his arms should be supported. To obviate any interference arising from shivering, the electrodes should be suitably warmed. Fig. 6 (Plate 1) shows the extent to which potential differences from this source may interfere with the electrocardiogram. In spite of every precaution it may be found very difficult to eliminate such spurious voltages entirely, for a certain amount of involuntary muscular activity is usually present in most patients.

(3) THE CATHODE-RAY OSCILLOGRAPH

(3.1) It is obviously desirable that supply voltages should be kept as low as possible, and therefore the C.R.O. used is of the low-voltage gas-focused type. It is found that with an anode voltage of 650 to 700 volts the brilliance of the spot, moving at such very low speeds, is perfectly adequate both for visual observation and for photographic recording of the electrocardiogram. With this kind of tube, used at this anode voltage, the sensitivity is approximately 0·5 mm movement of the spot on the screen per volt of difference between a pair of deflector plates; so that the total screen width, of rather more than 10 cm, represents a voltage-difference of about 200 volts. This figure should be kept in mind both for the problems of amplifier design and in the consideration of the circuits immediately concerned with the oscillograph. For example, it will be seen that to allow a spot movement which may cover the whole screen the supply voltage must be at least 800 volts, which will give a deflecting-plate voltage that is 100 volts above the potential of the anode, which itself represents a position of the spot approximately at the centre of the screen. This is the actual figure adopted.

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* See Reference (10). † *Ibid.*, (7). ‡ *Ibid.*, (9). § *Ibid.*, (17).

* See Reference (10). † *Ibid.*, (6). ‡ *Ibid.*, (10).

(3.2) The fluorescent screen of the oscillograph deserves special mention, since without its special properties the cathode-ray electrocardiograph would be a great deal less useful as a practical instrument. It incorporates a form of zinc sulphide, discovered and prepared by Levy,* which owing to the presence of a "phosphorogen" has an extremely long decay period, or afterglow. The C.R.O. with this special screen is classified by Messrs. Cossor, its manufacturers, as their Type G tube. Its afterglow image, with the tube a little shaded but in a normally lighted room, is plainly visible for 3 or 4 sec., which is amply long enough to allow quite detailed examination of the electrocardiogram as traced on the screen. The cathode ray gives, with the Type G screen, a brilliant blue immediate response of very good actinic value, followed—for the moving spot—by a bright green afterglow. Fortunately the actinic value of the afterglow is very low, so that there is no possibility of fogging when the tube is used for photographic recording, and special colour filters to obviate this are unnecessary. Some considerations of the merits and drawbacks of the cathode-ray image as an electrocardiographic recording will be put forward in Section (8).

(3.3) In the low-voltage gas-focused C.R.O., however, there is an inherent distortion which requires special treatment, namely "origin distortion." In the cardiograph, origin distortion in the x-axis is of little moment, since it will only be apparent when the spot is moving horizontally across the screen, as it is during direct visual observation of the electrocardiogram, so that only one small part of an electrocardiographic wave complex (near the centre of the tube) is distorted thereby. Such distortion is easily seen and can be readily discounted by the observer. But origin distortion in the y-axis is very important, since considerable, and constant, distortion of the electrocardiogram may arise from this cause. In the Cossor Type G oscillograph, origin distortion has therefore been eliminated (in the y-axis) by a method first described by von Ardenne; the reader is referred to his paper,* and to Fig. 7. Fig. 7 (*b*) illustrates the arrangement actually used in the Cossor Type G tube, where the bias half-plate (Y_{2a}) is joined to the anode internally, for convenience in manufacture. It will be noticed that, when this is done, twice as much negative potential has to be applied to the shift half-plate (Y_{2b}) to bring the spot to the centre of the screen, as compared with the original arrangement of von Ardenne [Fig. 7(*a*)]. This has the disadvantage that there may be some upset of spot focus in this, the important working, position of the spot. The sort of upset that occurs is a "whiskering" of the spot, caused by the extreme bending of the cathode ray during its passage through the deflecting field of the plates. In practice, however, it is not difficult to arrange for the biasing potentials to be such that the origins are sufficiently displaced to be outside the practical working area of the screen, without there being any upset of spot focus. No serious difficulties, of this kind, have been encountered by adopting this procedure in preference to that of a separate lead-out for the bias half-plate.

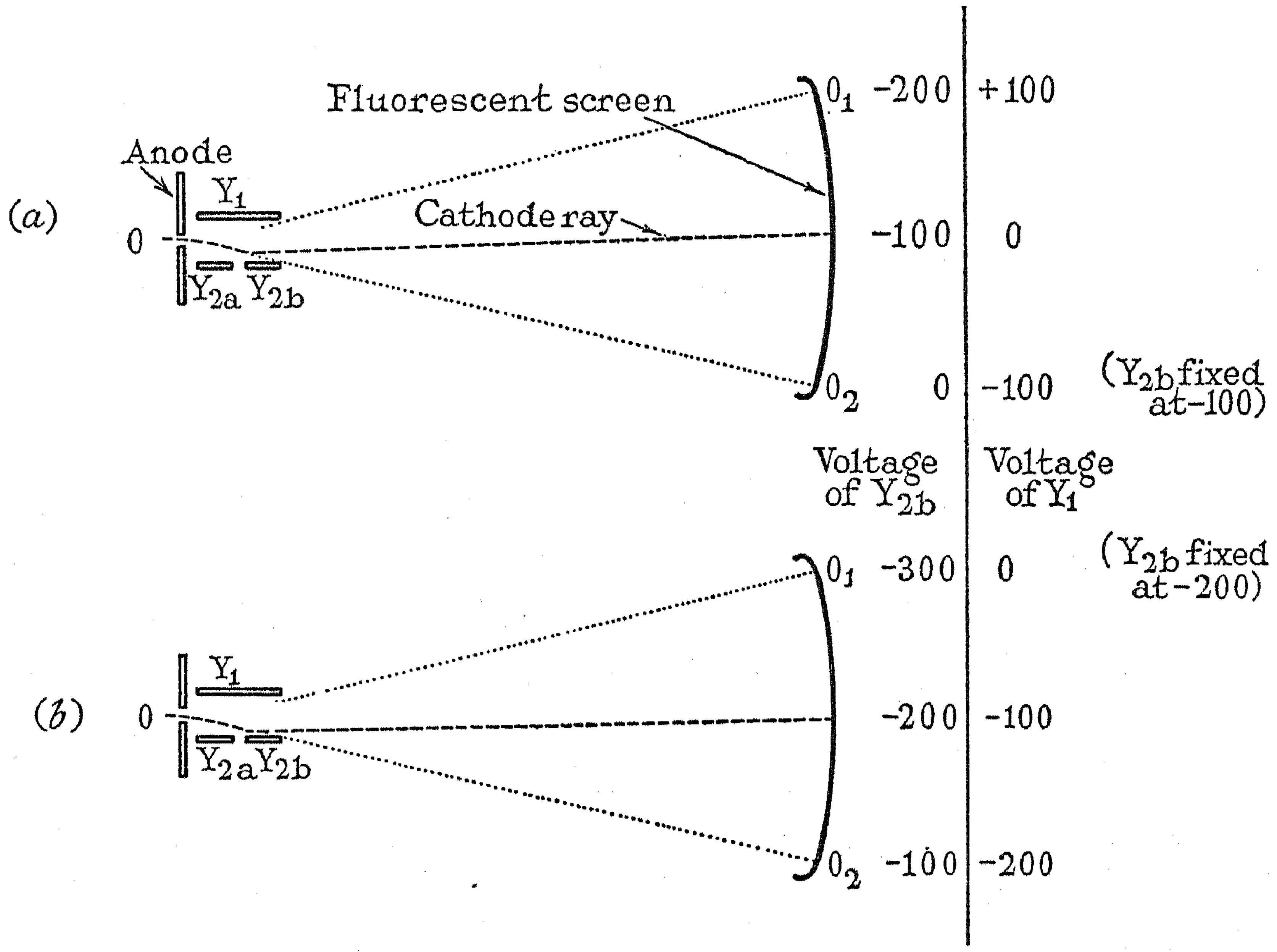

Fig. 7.—Method of overcoming origin distortion. (O_1 and O_2 are the points where origin distortion occurs; at O_1 there is an origin between Y_1 and Y_{2a}; at O_2 there is an origin between Y_1 and Y_{2b}.)
(*a*) Bias plate at + 100 volts. (*b*) Bias plate joined to anode. Here the mean potential of Y_1 is fixed at −100 volts.

(4) THE CIRCUITS IMMEDIATELY CONCERNED WITH THE CATHODE-RAY TUBE

(4.1) Filament

The oscillograph used in the earlier unit model cardiograph required accurate and variable control of the filament current to obtain good spot focus.† But with present-day tubes, as used in the combined model cardiograph, the filament does not require a variable control, so that a fixed resistor is all that is necessary; the filament ammeter can be dispensed with, and so a control is saved. Instead of the two accumulators, for the amplifier valves and for the C.R.O. filament, one large-capacity accumulator (unspillable fluid-acid type) is used, so that the C.R.O. filament is at the same potential as the filaments of the amplifier valves, namely earth potential. This is, of course, contrary to usual C.R.O. practice, where the anode is earthed, but no difficulties have been encountered by adopting it.

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* See Reference (8).

* See Reference (1).

† For a description of the earlier unit model cardiograph see Reference (22).

(4.2) Wehnelt Cylinder

The negative bias (from 50 to 100 volts) necessary for the shield is got by passing the current from the H.T. supply unit through a suitable potentiometer resistance, the top end of which is connected to filament (and earth) and the slider of which is connected to the shield. Unfortunately this arrangement has one important fault, that any variation of H.T. current, as happens during an upset to the amplifier (such as change of lead), will cause the potential between the ends of this resistance to vary and thereby upset the focus of the spot. This drawback has been surmounted, however, by using a neon stabilizer (Cossor, S. 130) with a high-resistance potentiometer shunted across it (Fig. 8). This scheme ensures that, whatever variation may occur in the H.T. current, the p.d. between the ends of the potentiometer will remain constant, so that the focus of the spot cannot alter.

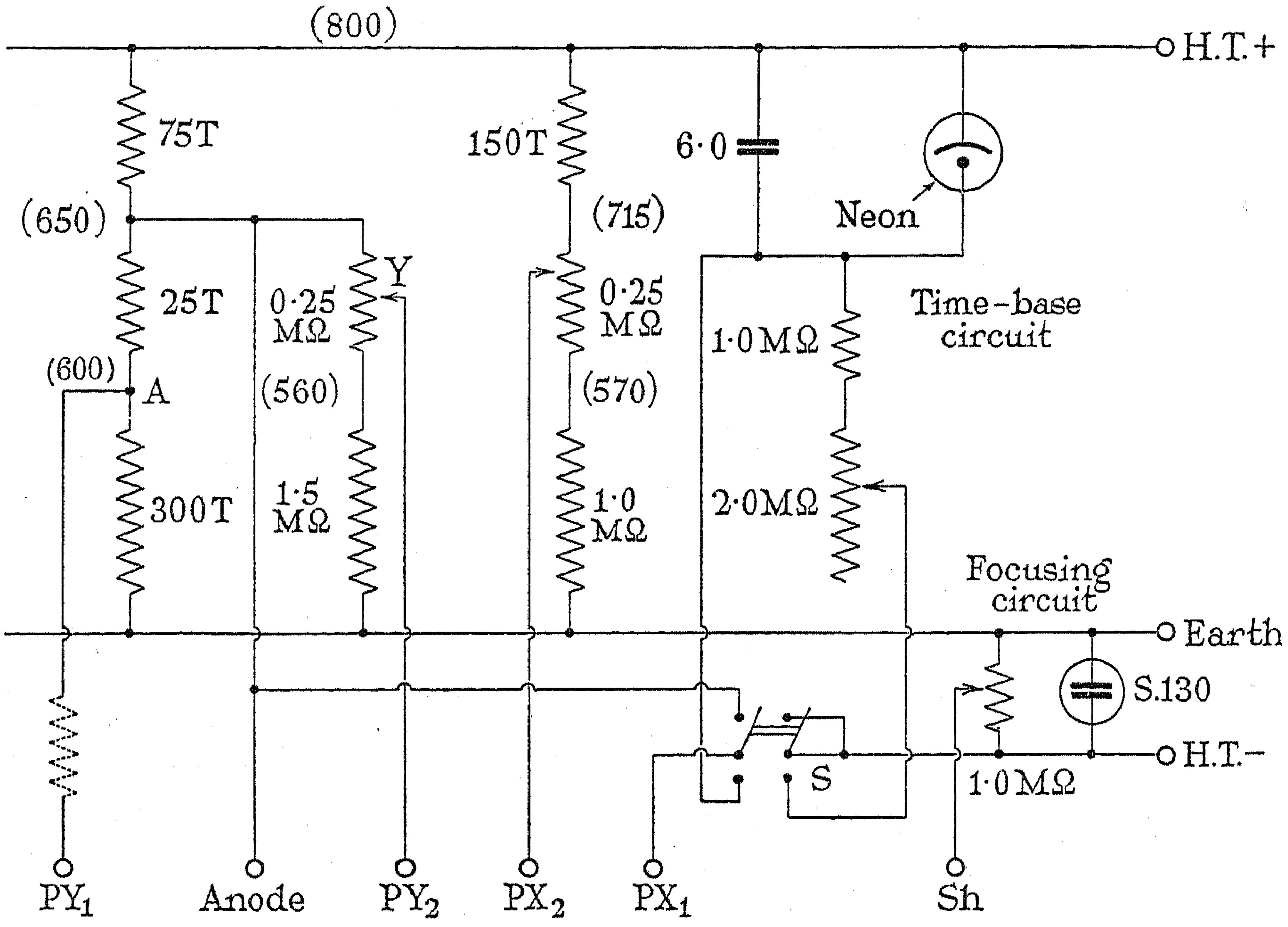

Fig. 8.—Circuits immediately concerned with the oscillograph. (Figures in brackets indicate potential, in volts, above earth.)

(4.3) Anode and Shift Potentiometers

Fig. 8 shows the arrangements for the voltage supplies for the anode and shift plates of the cathode-ray tube. It calls for no special comment except to note that the avoidance of origin distortion involves a rather more complicated resistance network than is usual. The figures in brackets indicate voltage above earth, and the plain figures the values of resistance used.

(4.4) Time-base Circuit

For visual observation of the electrocardiogram it is necessary to have a slow linear time-base motion, so that the spot may traverse the screen slowly, from left to right. It was considered that it would not be necessary for this time-base motion to be strictly linear, and in practice it was found that the simple method of slowly charging a condenser, and quickly discharging it by a neon discharge tube, gives a repeating time-base motion that is perfectly adequate for visual electrocardiographic work. The capacitance of the condenser and the size of the charging resistance have to be very much greater than is usual in oscillograph practice for the time-base motion to be slow enough, since the minimum speed of the spot must be rather less than 2 cm. per sec. A variable charging resistance allows the speed of the time-base motion to be under the control of the observer, and the series fixed resistance determines the maximum traverse speed available. Fig. 8 illustrates the time-base circuit also. When the electrocardiogram is to be recorded photographically, where accuracy is essential, the time-base is switched off and the working x-plate is joined to a point of the resistance network which will centralize the spot in the x-axis; movements of the spot are now confined to the vertical axis, and the time-base motion is provided by the strictly uniform movement of the recording paper. For convenience in use these operations are effected by a double-pole click switch (S), operated by the condenser charging resistance ("Velocity") knob in its extreme anticlockwise position.

(5) THE AMPLIFIER

(5.1) The working y-plate of the oscillograph is joined (via a condenser) to the output from the amplifier. It was considered that it would be wise to allow for approximately 6 cm. movement of the spot on the screen per millivolt of input. The gain of the amplifier must therefore be somewhere in the neighbourhood of 120 000 times, since it will be remembered that the sensitivity of the C.R.O. at the chosen anode voltage is about 0·5 cm. per volt. While working, the gain of the amplifier is exactly adjusted to 2 cm. per millivolt, which is twice Einthoven's standard. Thus doubling the size of the electrocardiogram makes its visual observation very much easier, and in recording photographically the camera lens reduces the cathode-ray image by exactly one-half, so that the recorded electrocardiogram is accurately standardized. Designing the amplifier for a gain of 6 cm. per millivolt gives a generous allowance for inevitable inequalities in components and a good margin of safety for decline in battery voltages; also, if desired, the electrocardiogram may be enlarged to practically any size required.

Although it would appear that a D.C.* amplifier is necessary for such a slow transient as the electrocardiogram, there are many reasons favouring an R.C.C. amplifier. The coupling batteries necessary for a D.C. amplifier add a great deal of extra weight. There are drifts of the baseline in a high-gain D.C. amplifier, caused by slight unevenness in the voltage of the H.T. battery supplying the first valve, which require constant adjustment, and, even with such a stabilizing scheme as that described by Matthews,† these necessitate several extra controls; obviously the number of controls must be made as few as possible in a practical instrument to be used by a physician, since he usually will not have any technical electrical knowledge. And with an R.C.C. amplifier there is the considerable practical advantage that adjustments for compensation of skin potentials are unnecessary—again a saving in the number of controls.

With an R.C.C. amplifier, however, it is a matter of extreme importance that the time-constant of the intercoupling condensers and grid-leaks is large enough to avoid any distortion of such a slow transient as the electrocardiogram. The value adopted is 4 sec., given by coupling condensers of 2 μF in series with grid leaks of 2 MΩ. Bedford and the author‡ found no appreciable distortion when using this time-constant, but the matter is so important that it will receive detailed consideration in Section (7). It will be readily appreciated that the use of such an exceptionally long intercoupling time-constant might cause trouble by the valves running into grid-current, from the accumulation of stray higher frequencies which have no time to leak away. So that, unless both the apparatus, and (what is a more serious practical consideration) the patient, are fairly carefully screened, the amplifier might be completely inoperative from this cause. The author therefore isolated each valve from such higher frequencies by using a fairly complete filter circuit, consisting of a resistance in series with the grid of the valve and a small condenser between grid and filament; a small condenser between anode and filament, in parallel (from the a.c. point of view) with the anode resistance, completes the filter. This last condenser is not part of the filter circuit concerned with the direct line of the amplifier, but serves to shunt higher frequencies from the line. Such higher frequencies may be either strays picked up by the H.T. dry battery, or are random effects produced in the anode resistances of the valves. The anode resistances used are carbon-element resistors which, it is well known, are prone to suffer from such defects; wire-wound anode resistances would possibly be satisfactory without the small condenser, but, as they are more bulky and it was found that the amplifier was quite steady as arranged, they were not used. The filter-circuit time-constants must also be so chosen that there is no distortion of the higher-frequency components of the electrocardiogram, and these will likewise be considered in Section (7).

The amplifier of the cardiograph therefore has three stages, resistance-capacitance-coupled, and with R.C.C. coupling to the cathode-ray tube. The first two stages are battery-supplied 2·0-volt triodes (R.C.C. valves) and the last a 2·0-volt screen-grid tetrode.* The use of such a high-impedance output valve is only made possible by the very high input impedance of the C.R.O. Fig. 9 gives a basic circuit diagram of the amplifier. It will be noticed that whereas grid bias for the last valve is obtained from the ordinary small dry cell, the grid bias for the second valve is got by a more uncommon method. The very high ohmic value of the grid leak (10 megohms) allows the accumulation of electrons on the grid of the valve, so that its potential remains appreciably below that of the filament; on the other hand, there is sufficient leak for the bias to remain constant. The first valve has no negative bias at all; its grid return actually goes to a point which is 1 millivolt positive to earth (see the calibrating circuit, Fig. 10). This arrangement may call forth some criticism, but the author has found no difference in the electrocardiogram when this valve is biased. It will be realized: (i) that the grid of the valve is at a potential considerably below the *mean* potential of the filament; (ii) that the grid swing is extremely small—a matter of 2 or 3 millivolts maximum; (iii) that valves vary greatly in their grid-current starting-point, so that provided a valve is chosen with a high enough grid-current starting-point there will be no lack of linearity in its grid-volts/anode-current characteristic over such an extremely small grid-swing.

The gain control is by a very usual method; its working is quite obvious from the circuit diagram (Fig. 9).

For its steady working, which is a *sine qua non* for electrocardiography, there are many small practical points which are essential in a high-gain amplifier of this type. The filament circuits, operating at comparatively low voltage and large current, are particularly important. For example, it was found essential that the first valve should be soldered into its holder; that the L.T. switch should have a very positive action and have unusually large contacts; that the components of the filter circuit should be as near their respective valve pins as can be conveniently arranged; best-quality resistances are essential; and so on. Even then, when the amplifier is working at high gain, there is slight unsteadiness of

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* Direct-coupled.

† See Reference (13).

‡ *Ibid.*, (22).

* See Reference (14).

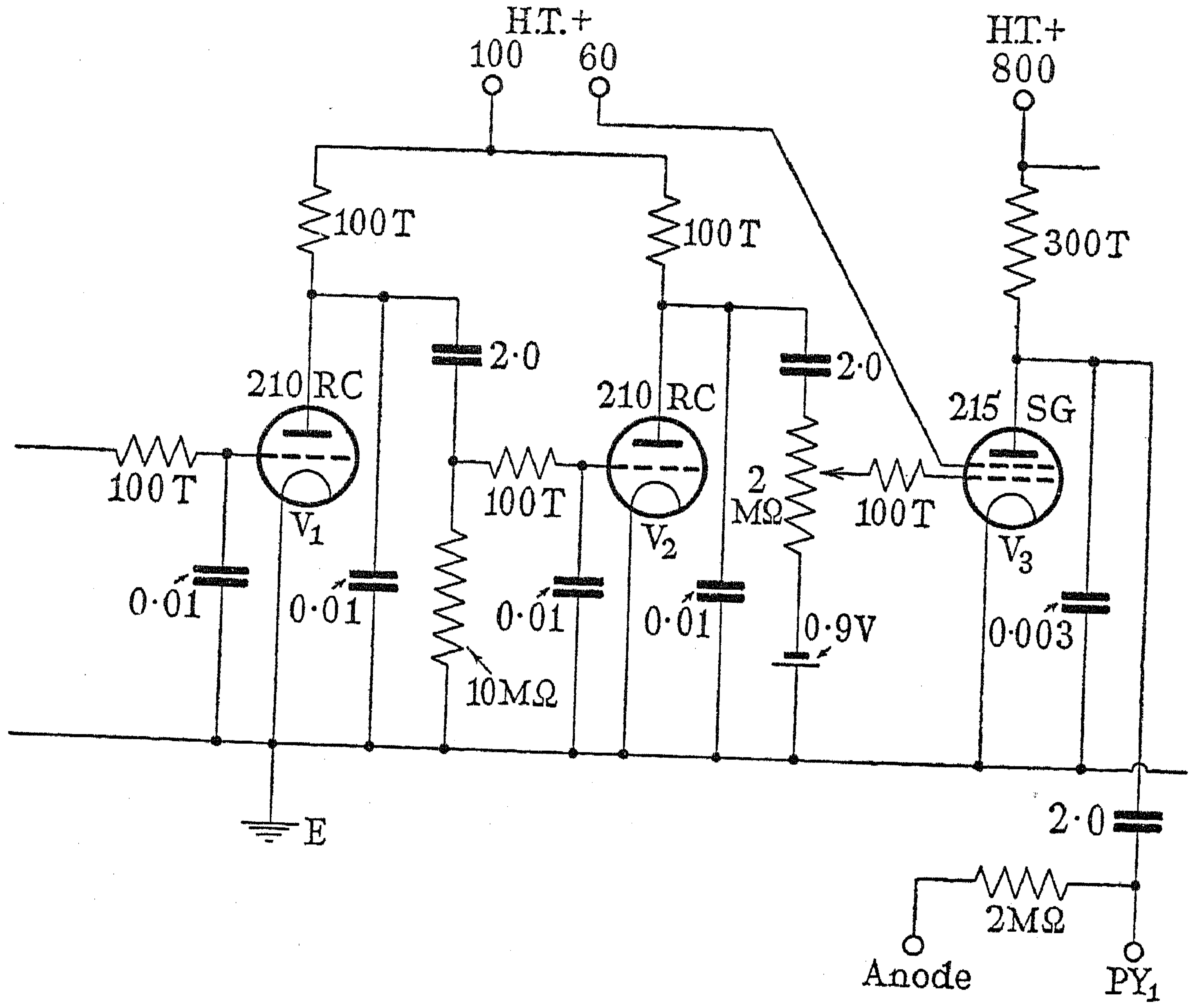

Fig. 9.—Basic circuit diagram of amplifier.
T = 1 000 ohms.

the spot, intrinsic in the amplifier and possibly due to "flicker" effect.* Many of these points have already been noticed by Caldwell, Oler, and Peters, and are well described in their paper.† Their amplifier, which was designed for use with a Westinghouse mechanical oscillograph, had four stages and was resistance-capacitance-coupled. But they did not limit its high-frequency response by filter-circuit arrangements, and they note that their amplifier was very sensitive to microphonic effects. Their intercoupling time-constant (0·5 to 1·5 sec.) appears to the present author to be rather short, although it must be agreed that their published electrocardiograms show none of the stigmata of low-frequency distortion [see Section (7)].

(5.2) Some account should be given of the calibrating circuit, by which the gain of the amplifier may be adjusted so that 2·0 cm. movement of the spot on the screen represents a p.d. of exactly 1 millivolt between the grid and filament of the first valve. It is illustrated in Fig. 10, which is self-explanatory. It will be realized that when the calibrating key is pressed down, momentarily short-circuiting the 1-ohm resistance, a negative pulse of 1·0 mV is transiently presented at the input of the amplifier; the same thing occurs during the upward release of the key. For it will be remembered that the electrocardiogram represents negative voltages as being above the baseline, so that, as the spot should preferably move upwards during calibration, the momentary pulse of 1·0 mV must be a negative one. The 10-ohm resistance is included so that small differences of resistance in the key contacts will not upset the constancy of the calibrating voltage.

With the string galvanometer, the usual method of calibration is by putting the calibrating voltage directly in series with the patient, and then adjusting the string tension so that the whole electrocardiogram moves 1·0 cm. for 1·0 mV of calibrating voltage. Strictly speaking, therefore, the author's method of calibration does not allow a true comparison of cathode-ray electrocardiograms with string-galvanometer records. But it is equally true that successive string-galvanometer records are no more comparable, since this method of calibration presupposes that the resistance of the patient circuit is constant at different sittings. Sufficient evidence has been put forward in Section (2) to indicate that this is by no means necessarily the case, even using non-polarizable electrodes. In actual practice there is very little difference between the records from this cause. Far bigger differences are caused by the diverse high-

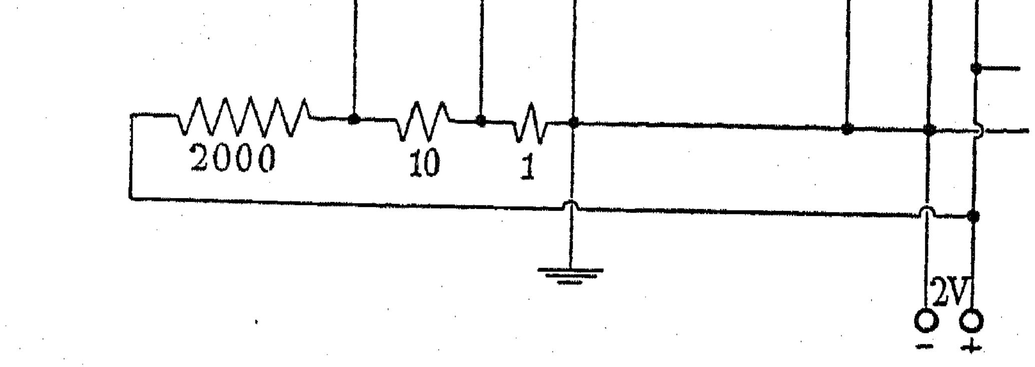

Fig. 10.—Calibrating circuit.

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* See Reference (15).

† Their work was unknown to the author at the time when the major part of the experimental work on the cardiograph amplifier was being done.

frequency responses of the two instruments; this matter will be considered in Section (7).

The input circuits include a lead switch by which the patient voltages from the various leads may be quickly connected to the amplifier. When the lead is changed, it is found that the sudden large change of potential, due to the differing skin potentials of the two leads, completely paralyses the amplifier for a short period; but it is only necessary to wait for about 30 sec. for the amplifier to settle down again to its new conditions. Nevertheless, in clinical practice even this short wait between leads is irksome, and it would be a considerable practical advantage if it could be eliminated. Brookes-Smith has devised a scheme whereby the lead can be immediately changed without upsetting the amplifier; broadly speaking, it is effected by isolating the patient from the grid of the first valve by large-capacitance condensers. This condenser input circuit is, however, peculiarly sensitive to leakage (from the H.T. battery supplying the first two valves), and it is essential to take special precautions in insulation if distortion is to be avoided.

(6) HIGH-VOLTAGE SUPPLY: METHODS OF DEALING WITH INTERFERENCE

(6.1) In the early stages of the amplifier the main essential is absolute steadiness. Accordingly the first two valves are supplied by an H.T. dry battery, which need only give 100 volts and be of low capacity, since the total anode current of these two valves is less than 1 mA. But the cathode-ray tube circuits require 800 volts to give the requisite 650 to 700 volts for the anode of the tube: and if such high voltage is available it will be an advantage to make use of it for the supply of the output valve (screen-grid tetrode), since its efficiency may be greatly improved thereby.* It was necessary, therefore, to arrange for an H.T. supply at 800 volts (with a current of 6 to 7 milliamps.), suitably portable and workable from any electricity supply, so that the cardiograph might be used anywhere, from a hospital to a cottage. It was considered that it would be best for the H.T. supply to be housed in a separate unit, for a visiting physician might one day be in a house supplied by direct current and on another in one supplied by alternating current. It was also necessary to consider the problem of easiest portability for country houses and cottages where no electricity mains are available.

From the standpoint of portability, alternating current presents no difficulty (complications arise from interference, which is to be considered immediately), but the problem for the country cottage and for d.c. mains is not so easy. After some experiment it was decided to use a small rotary convertor arranged for an input of 12 volts. In this way it is possible to run the convertor from the usual motor-car battery, carrying the high-voltage output into the patient's house by a conveniently arranged reel of well-insulated cable. Alternatively, a good-sized 12-volt battery may be used, but of course this detracts from the portability of the whole apparatus. With d.c. mains the same convertor is run via a variable power resistance; a voltmeter across the input of the convertor shows the correct setting for the resistance and also serves to indicate the polarity of the mains. This arrangement has proved on the whole very satisfactory, but it was nevertheless found essential to decouple the convertor from the cardiograph, since a good deal of interference at fairly high frequency is generated by the secondary commutator of the convertor; a small condenser between H.T. negative of the convertor and the earthed case, and a low value of stopping resistance in the negative H.T. lead, proved entirely effective.

(6.2) Alternating current at 50 cycles per sec. (or, still more so, at 25 cycles) is well within the frequency response of the amplifier, and, where the cardiograph is being worked in the vicinity of a.c. mains, may cause such severe interference that the electrocardiogram is virtually unreadable. This interference shows itself as a thick "mush" area caused by the comparatively rapid sine-wave motion of the cathode-ray spot, upon which the electrocardiogram is superimposed. It is, of course, perfectly feasible to get over such difficulties by appropriate shielding, but any scheme of shielding must include the patient, so that in practice shielding will probably not be used except as a last resource. Previously it was often essential for the physician, when working in the vicinity of alternating current, to switch off the supply at the mains before his electrocardiograph could be used.

Interference may be either magnetic or electrical; and electrical interference may be either resistive (in phase with the mains) or reactive (90° out of phase with the mains). In this last case the interference is picked up capacitatively, since the surface area of the patient is quite considerable; when the patient is sitting in the proximity of a wire connected to the a.c. mains—whether carrying current or not—the pick-up may amount to as much as 4 or 5 millivolts between the hands, or between either hand and the foot. Resistive pick-up is caused by leakage to the patient from the live pole of the mains, and occurs at its worst in old-fashioned houses where the wiring is not enclosed in earthed conduits. In practice it is found that electrical pick-up is a mixture of its reactive and resistive components.

Magnetic interference is not so commonly encountered, since it will only occur where there is a magnetic field, such as is caused by the proximity of electrical apparatus, e.g. an X-ray transformer, lift, etc. And even then, unless such a field is strong, it will only be troublesome if the cardiograph is situated at some distance from the patient, so that a looped circuit is formed. It is usually not difficult to overcome such troubles by suitably disposing the cardiograph and the patient. Obviously the patient must not be situated too near the a.c. mains unit (because of the magnetic field of the transformer), neither should the mains unit be very near the cardiograph, since the cathode-ray tube (unless specially guarded by a mumetal shield) will suffer direct magnetic interference.

The cure of electrical interference is effected by arranging a circuit which will oppose the interfering sine-wave voltage by a sine-wave voltage of the same frequency equal in amplitude and opposite in phase.

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* See Reference (14).

In other words, the vector sum of the resistive and reactive components of the interfering voltage must be exactly opposed by a voltage vector of equal length. There are many circuits which can be arranged for this purpose. One of the simplest of these is shown in Fig. 11, which illustrates their principle very well. The middle points of each resistance (R_1 and R_2) are at earth potential; the voltage across R_1 is in phase with the mains voltage and opposes the resistive component of the interfering voltage, while the voltage across R_2 is nearly 90° out of phase with the mains and opposes the reactive component. The presence of resistance (R_2) in the reactive circuit upsets the exact quadrature of the voltage, but as a practical disadvantage this is not serious, and it can be quite easily corrected (if desired) by introducing an equivalent amount of inductance in the circuit of R_1. This "mush" neutralizing circuit is either introduced in the earthy lead from the patient, as in the diagram, or the correcting voltage may be injected at the grid of the valve via a small condenser. The latter scheme has the advantage that the voltage from the "mush" neutralizing circuit is easily limited by varying the size of the condenser. Fig. 12 (Plate 1) shows how well a.c. interference is eliminated by this means.

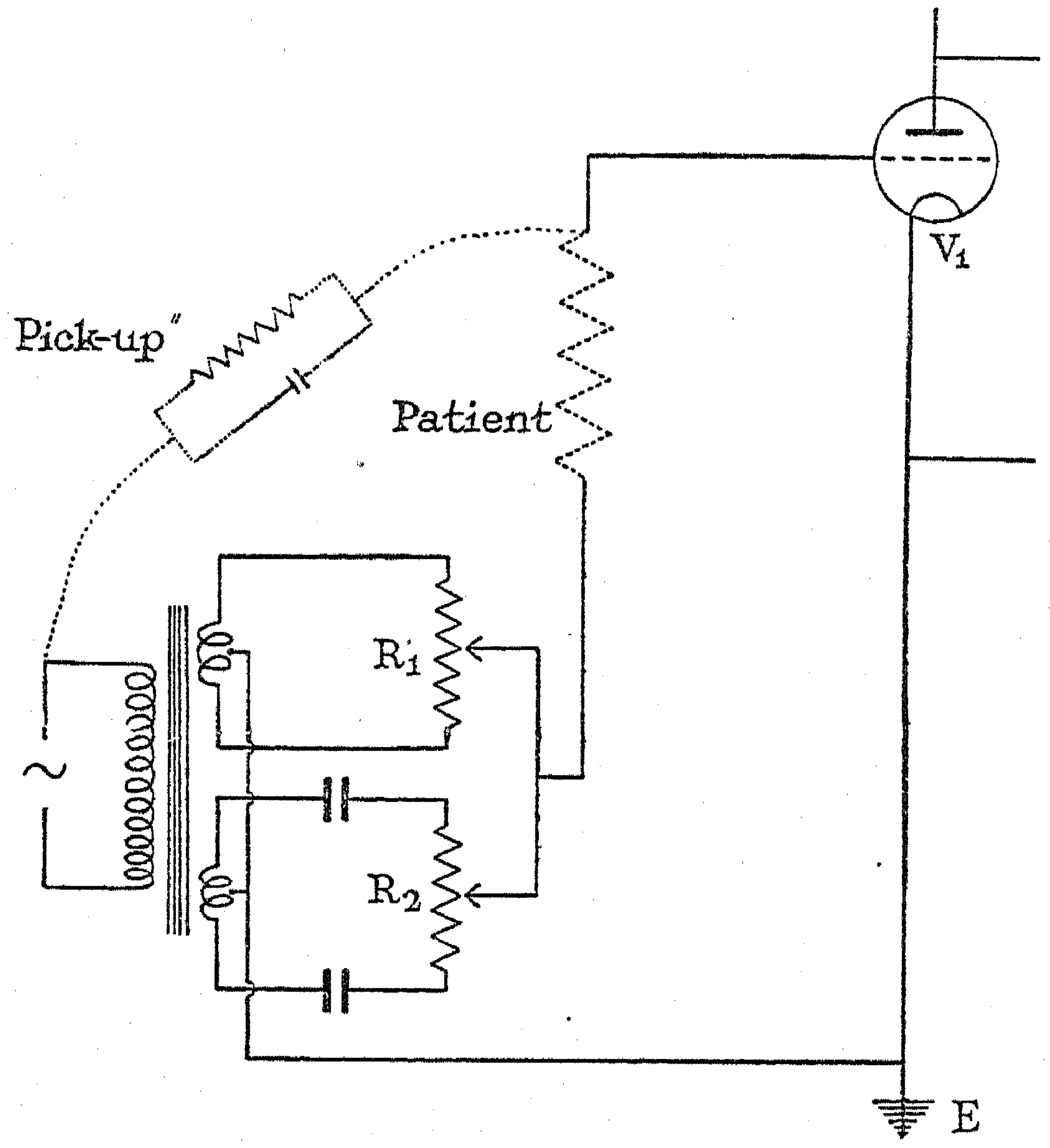

Fig. 11.—Basic circuit of a.c. "mush" neutralizing device.

One point of practical importance should be mentioned in connection with such "mush" neutralizing circuits. They are entirely effective for a pure sine-wave interference, whatever its frequency, since the neutralizing circuit is fed from the same a.c. source as the interfering voltage. But they are not so effective if the interference is not a pure sine wave; in that case harmonics of the main frequency will cause trouble. Keeping the resistance of the patient circuit as low as possible, by careful attention to the electrodes [see Section (2)], will minimize such troubles by keeping the voltage across the patient (generated by such leakage currents) at as small a value as possible. The advantages of a balanced amplifier for the elimination of all these spurious voltages will be immediately evident, and work is at present in progress on the design of such an amplifier for electrocardiographic purposes.

(7) FREQUENCY CHARACTERISTIC OF THE AMPLIFIER: RESPONSE TO A HEAVISIDE TRANSIENT*

It will readily be appreciated that, however convenient the cathode-ray electrocardiograph may be in practice, it would be intolerable if it were demonstrated that electrocardiograms taken with it were materially distorted. The cathode-ray oscillograph (with origin-distortion errors corrected) is of course itself entirely free from distortion, since it is free from inertia, and thus intrinsically without any natural period. There is therefore some justification for a fairly careful examination of distortion tendencies in the amplifier, which is practically the only part of the apparatus where they can originate.†

The calculated frequency characteristic of the amplifier, as obtained from the basic circuit diagram of Fig. 9, and with resistance and capacitance values as shown, is given in Fig. 13. It will be observed that it is materially flat from 0·1 to 30 cycles per sec. The equivalent of the string deflection time (of the string galvanometer) in cycles per sec. is a quarter of a cycle—that is to say, one cycle between 0 and $\pi/2$ radians—so that 30 cycles per sec. are equivalent to a string deflection time of 1/120th (0·0083) sec. The high-frequency response, reckoned on this basis alone, is therefore very good when compared with that of electromechanical electrocardiographs, and is of course completely aperiodic; moreover, it may be raised as required (until stray capacitances become operative) by merely lowering the time-constants of the filter-circuit units. The author has been more concerned with the possibility of low-frequency distortions, caused by the choice of too short an intercoupling time-constant. An experimental amplifier was therefore constructed, using an early amplifier-unit‡ chassis as its basis, by means of which the capacitances of the intercoupling condensers (and also those of the filter-circuit units) could be quickly changed as required. The results obtained immediately showed that doubling or even quadrupling the intercoupling time-constants of the amplifier made inappreciable difference to the recorded electrocardiogram.

But although it is true that the frequency characteristic of the amplifier contains implicitly all the information necessary for an understanding of its behaviour, a far more informative theoretical examination is given by a consideration of its response to a transient. Taking, therefore, a Heaviside transient, where the voltage is raised abruptly from zero, at time $t = 0$, to some arbitrary value and maintained at that value indefinitely, we wish to examine the output voltage at various times after the transient has been presented at the input of the amplifier. The theory has been elegantly propounded by Bedford and Puckle,§ and will not be recapitulated here. Calculations from their formulae, using the time-constants of the cardiograph amplifier (Fig. 9), give the curves of Figs. 14 and 15 respectively for the high- and low-frequency responses to such a transient. It will be realized that Fig. 14 is really only an approximation, since there are not the straightforward equivalent circuits which properly justify such a calculation; and even Fig. 15 is not strictly correct because it is calculated for three stages of condenser-resistance couplings each of time-constant 4 sec., whereas the coupling between V_1 and V_2 has really a much higher time-constant.

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* See also Reference (23).

† Considerable distortions may be caused by unsuitable patient electrodes. This subject has been discussed in some detail in Section (2).

‡ See Reference (22).

§ *Ibid.*, (2).

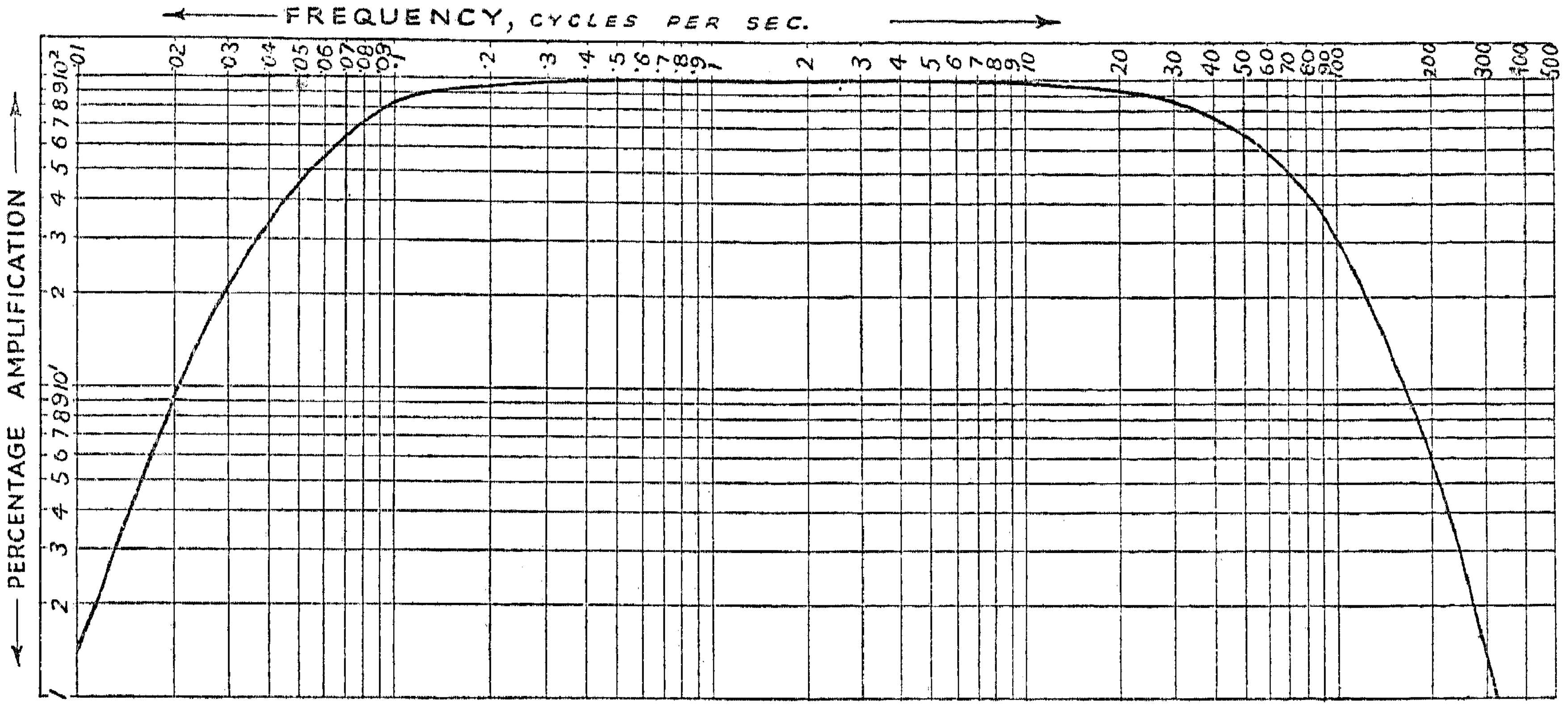

Fig. 13.—Frequency characteristic of amplifier.

It appeared to the author worth while to verify these theoretical results by experiment, and Figs. 16 and 17 (Plate 2) show photographs of cathode-ray oscillograms which are striking practical confirmations of the theories. Fig. 17 is given by a transient simply obtained from the ordinary calibrating circuit. But the quick transient necessary for the high-frequency response curve of Fig. 16 had to be achieved by a special circuit (suggested by Mr. Bedford) consisting of a high-frequency pentode with sufficient a.c. voltage applied to the grid to over-saturate it, so that the sharp bends at the bottom and top of its characteristic curve will give adequate rectilinearity to represent the required transient. The usual synchronizing arrangements allowed a standing picture to be obtained, and the flyback of the cathode-ray spot was modulated out. A suitably small fraction of the anode voltage was fed to the amplifier to give the response curve.

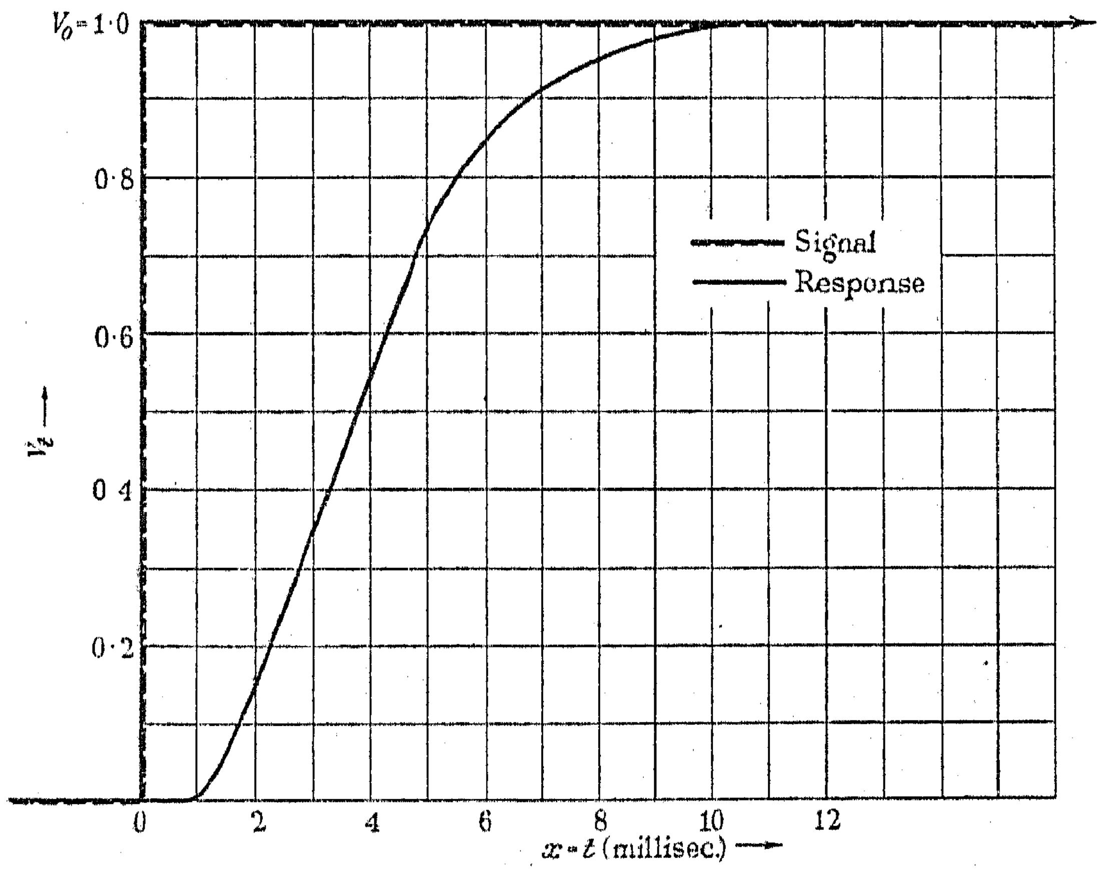

Fig. 14.—High-frequency response of amplifier to Heaviside transient, $V_t = V_o\left[1 - \varepsilon^{-x}\left(1 + x + \frac{x^2}{2} + \frac{x^3}{6}\right)\right]$.

Although these methods are very valuable in giving a clear indication of the performance of the amplifier, they are rather unnecessarily severe for practical electrocardiography, since the electrocardiogram is not a strictly "right-angled" transient like the classical Heaviside transient. Obviously the most valuable information will be given by reproducing artificially a transient which resembles the normal electrocardiogram itself. For this purpose the author has constructed, with the valuable assistance of Dr. F. Postlethwaite, a quite simple "artificial patient"* consisting of a photocell arrangement with a rotating asymmetrical disc, so shaped that it cuts off the light (during its rotation) in such a way as to imitate the normal electrocardiogram. The photocell current is then amplified by a simple one-stage amplifier; the voltage variations across the whole of the anode resistance of this amplifying valve are

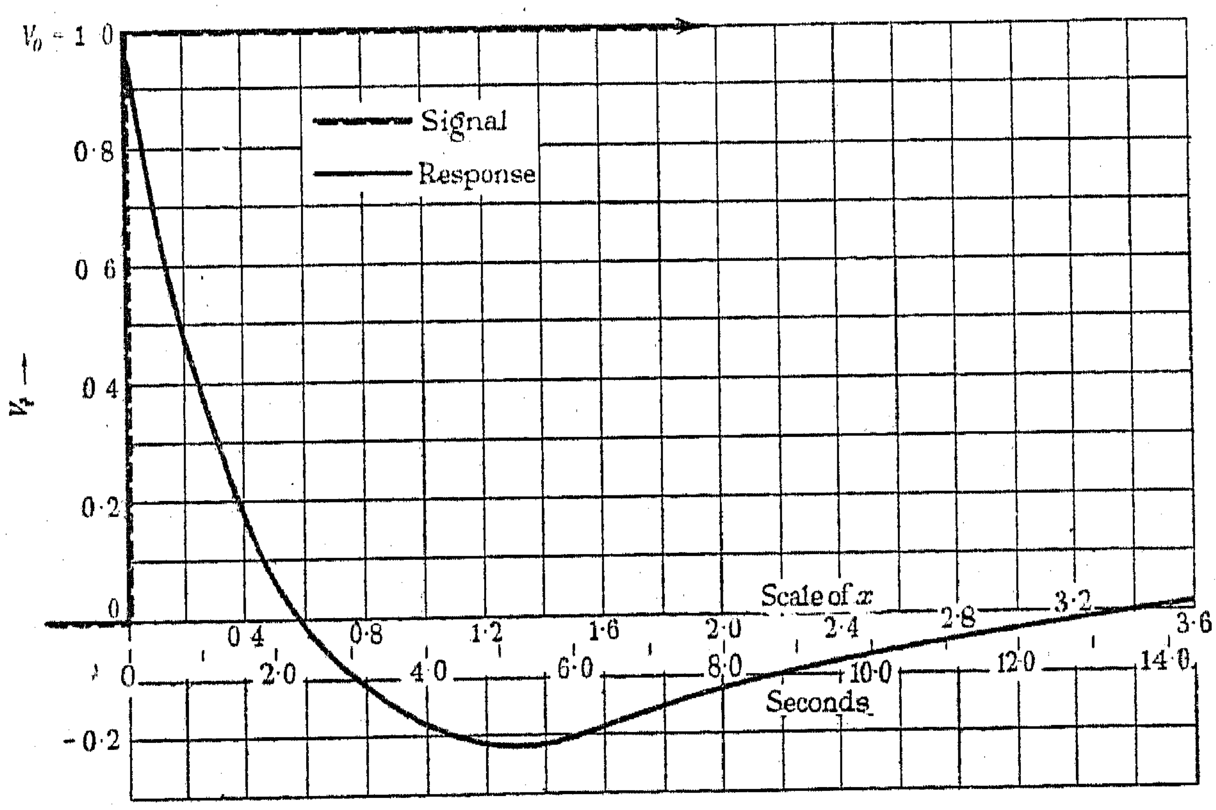

Fig. 15.—Low-frequency response of amplifier to Heaviside transient, $V_t = V_o[\varepsilon^{-x}(1 - 2x + \frac{1}{2}x^2)]$.

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* See also Reference (23).

fed to a separate C.R.O. which constitutes the control, and a small fraction of the anode voltage is fed to the cardiograph amplifier for the examination of the response. The curves of Fig. 18 (Plate 2) show some of the results obtained, using this machine in conjunction with the experimental amplifier, and illustrate very well the distortion produced by having too short an intercoupling time-constant. The signs of low-frequency distortion which are immediately evident are the increased depth of the "S" peak and the trough after the slow "T" wave, together with the slow recovery which gives an "uphill" appearance to the whole picture. The curves show, too, that there is inappreciable difference when the chosen intercoupling time-constant is doubled (from 4 sec. to 8 sec.). The reason that the intercoupling time-constants are kept as low as possible, consistent with the avoidance of distortion, is that the time of waiting after a major upset to the amplifier, such as change of lead, should be as short as possible. With the adoption of such a scheme of lead switching as that of Brookes-Smith [see Section (5.2)], or any similar scheme, where the amplifier is not upset during the change of lead, it would be practically possible to increase the intercoupling time-constants to any desired extent; but it must be agreed that the present time-constant of 4 sec. per interstage gives quite inappreciable distortion.

Fig. 19 (Plate 3) shows the effect of changing the high-frequency response by altering the filter-unit time-constants, using this time a real patient; the curves show that the chosen time-constant of 0·001sec. does not give appreciable cut-off of the higher-frequency components of the electrocardiogram (notably the "R" peak), and they also show the sort of unsteadiness of the baseline which may appear when the cut-off is arranged to be at too high a frequency. These random oscillations of the spot are probably caused by action-potentials from minor muscle tremors of the patient. Future research may show that it may be desirable for such details to be included; but for present-day electrocardiography they are best attenuated, since the clean appearance of the curve is spoilt by their presence. If their inclusion appears desirable it will be an extremely simple matter, in the cathode-ray electrocardiograph, to raise the frequency response of the amplifier to any extent that is required, by merely shortening the filter-circuit time-constants.

It is interesting to compare the high-frequency response of the author's cathode-ray electrocardiograph (with its artificially-introduced electrical equivalent of inertia) with that of the classically-used string galvanometer, and the curves of Fig. 20 (Plate 3) illustrate this very well. They show very clearly how distortions of quick-moving electrocardiograms may be caused by the momentum of the string.

(8) PHOTOGRAPHIC RECORDING OF THE CATHODE-RAY ELECTROCARDIOGRAM

Although the facility of immediate visual observation of the electrocardiogram makes the cathode-ray electrocardiograph a valuable clinical instrument, it is even more important for the physician that the permanent photographic records produced with it should be clean, clear, and accurate.

The camera of the cardiograph is an integral part of the instrument.* It is arranged to work with special bromide paper (prepared by Ilford, Ltd.) of standard cinema width (35 mm.); this is supplied in 25-ft. rolls, which are comfortably adequate for the recording of the electrocardiograms, in all three leads, of 8 or 10 patients. As described in Section (4.4), when the electrocardiogram is to be recorded the spot is kept stationary in the x-axis, so that its movements are confined to the vertical axis of the tube and are now exactly comparable to the excursions of the string of the string galvanometer—except, of course, that they are very much greater. The clockwork motor of the camera moves the paper past the recording position at exactly 2·0 cm. or 4·0 cm. per sec., the choice of speed being controlled by a simple change-speed mechanism in the camera motor.† The lens reduces the cathode image exactly in the ratio of 2 to 1, thus ensuring that if calibration [see Section (5.2)] has been accurately carried out, so that the spot moves 2·0 cm. on the screen per millivolt (two short lines are ruled 2·0 cm. apart on the end of the C.R.O. to facilitate this operation), the recorded electrocardiogram exactly conforms to Einthoven's voltage standard [see Section (1)]. Although really unnecessary with these invariable paper speeds, a time marking is recorded directly on the paper in the form of vertical lines at 0·1-sec. intervals. Light-tight storage and receiving cassettes for the sensitized paper allow daylight loading and adjustments of the camera. The receiving cassette will hold more than 6 ft. of record and has special spring guides which are completely successful in preventing jamming of the paper. There are also other details which make for ease and speed in operation.

A clear black-on-white photographic record of the electrocardiogram depends entirely on a correct exposure combined with the right developer.‡ As the actinic quality of the cathode-ray spot varies considerably from tube to tube, it is essential to have an iris diaphragm attachment (or some other arrangement for varying the aperture of the lens) so that the lens may be stopped down to give just the correct exposure; in addition, the aperture of the lens has to be suited to the speed of the recording paper. The image of the spot has such good actinic value (with present-day Type G tubes) that if such measures are not taken the picture will be over-exposed, and over-exposure shows itself as a peculiarly objectionable blurring of the edges of the electrocardiogram. Quite a number of published cathode-ray electrocardiograms show this fault, which is all the more inexcusable in that with a little care it is quite easily avoidable. It will in general be easier to get a clear black-and-white electrocardiogram with a shadow recording instrument, such as the string galvanometer, but with the light recording of the cathode-ray electrocardiograph a beautifully clean black-and-white picture with a much thinner baseline can be obtained by attention to such small details of technique, and it must be agreed that the few cathode-ray electrocardiograms

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* The camera of the original cardiograph was a separate unit [see Reference (22)].

† In the redesigned cardiograph the rate of paper movement is completely variable, and there is accordingly an independent time-marker.

‡ The author has found that a simple amidol developer (with extra bromide) gives the starkest black-and-white records.

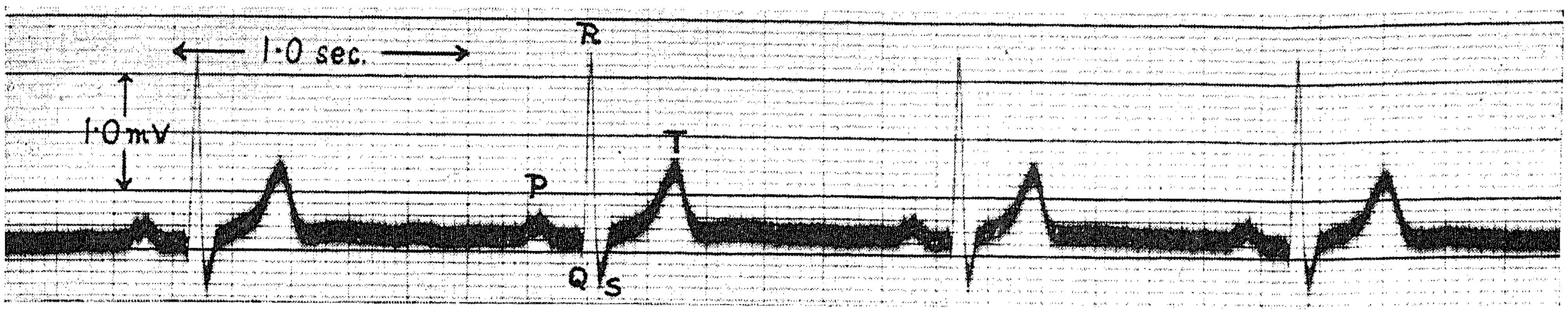


Fig. 2.—String-galvanometer record, Lead II.

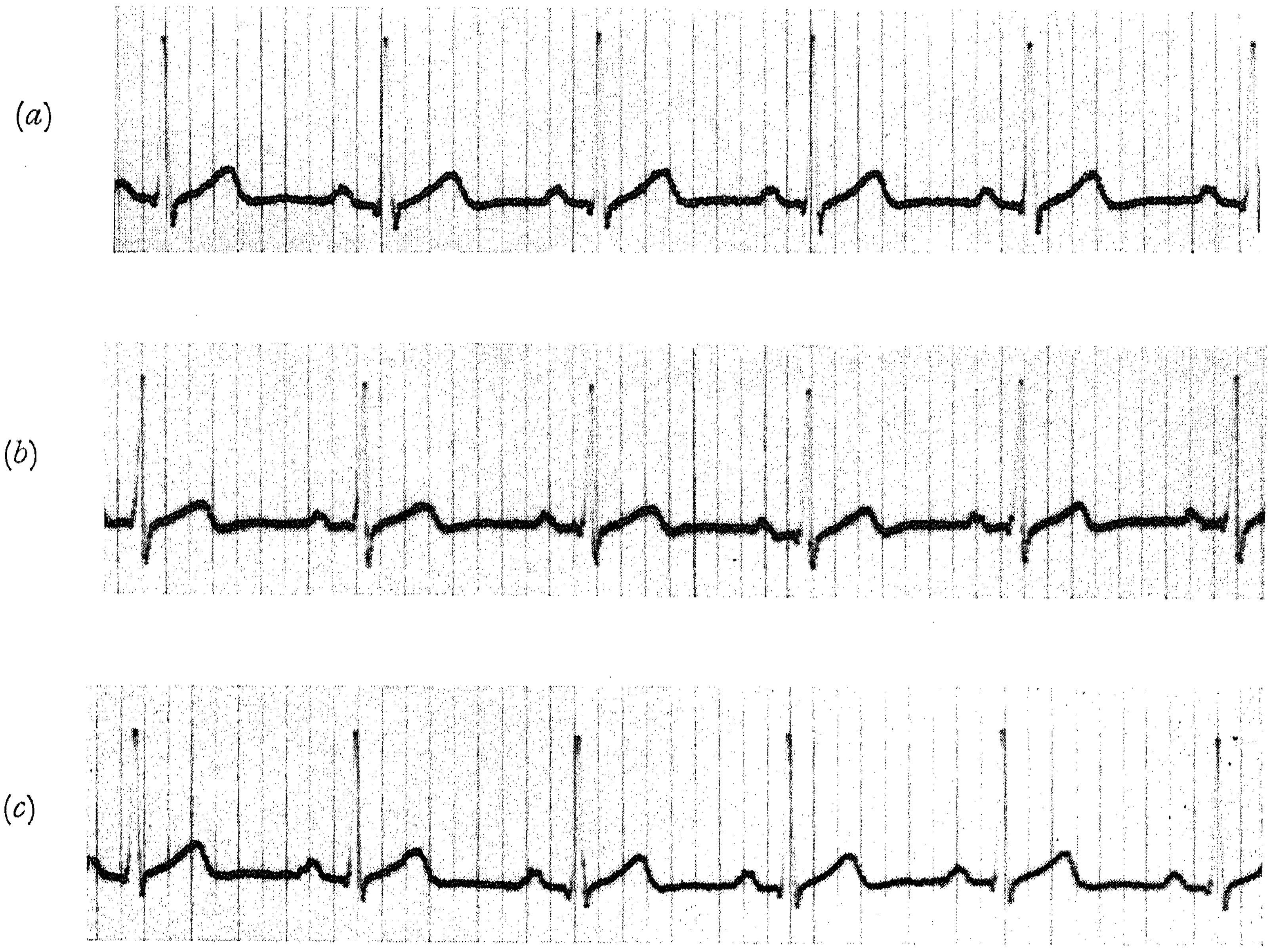


Fig. 5.—Electrocardiograms illustrating electrode distortions (Lead II).
(*a*) Saline pads. (*b*) Metal electrodes (german silver). (*c*) Metal electrodes with "Cambridge electrode jelly."

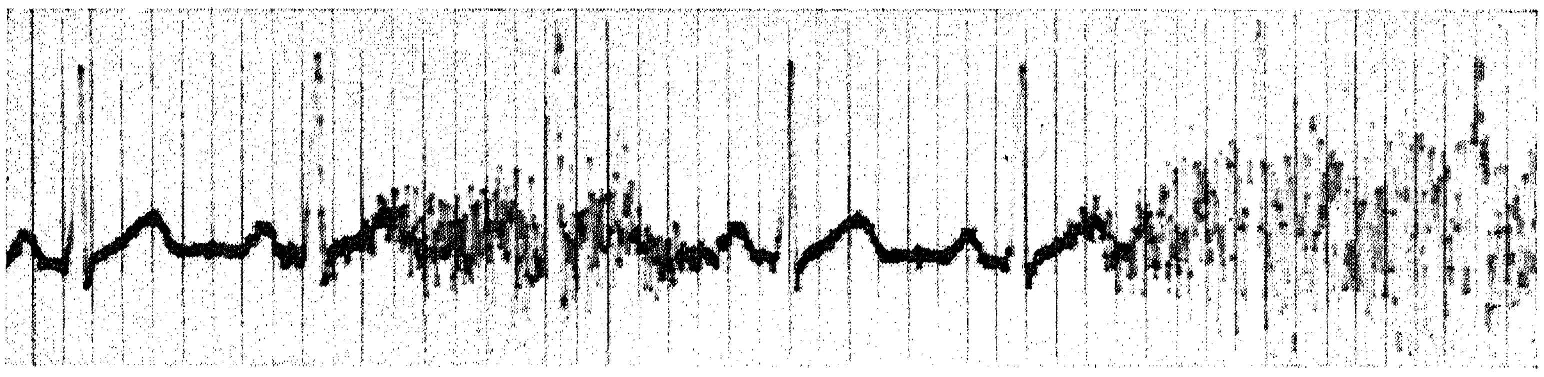


Fig. 6.—Somatic muscle action-potentials.

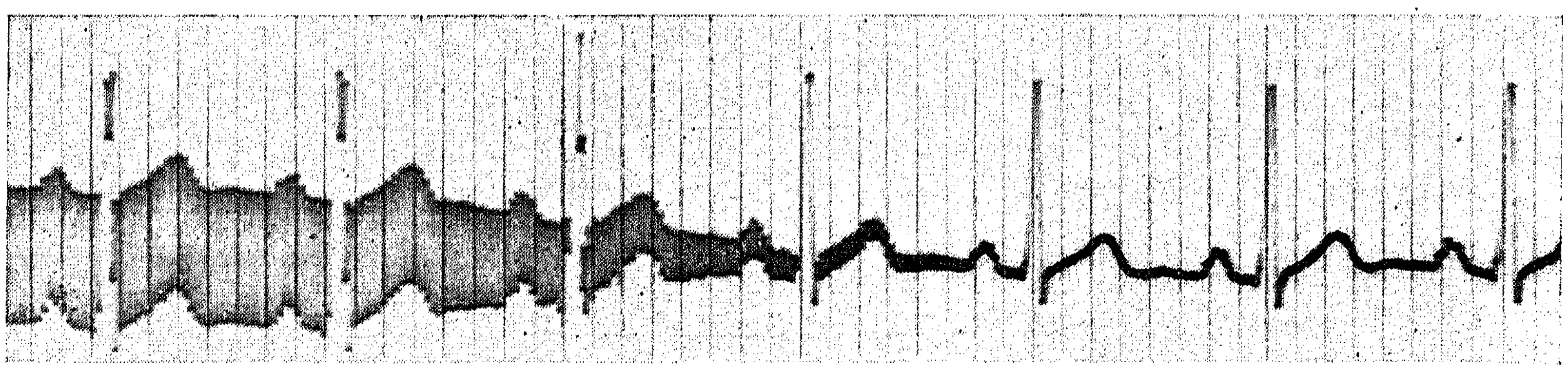


Fig. 12.—Neutralization of interference picked up from a.c. mains.

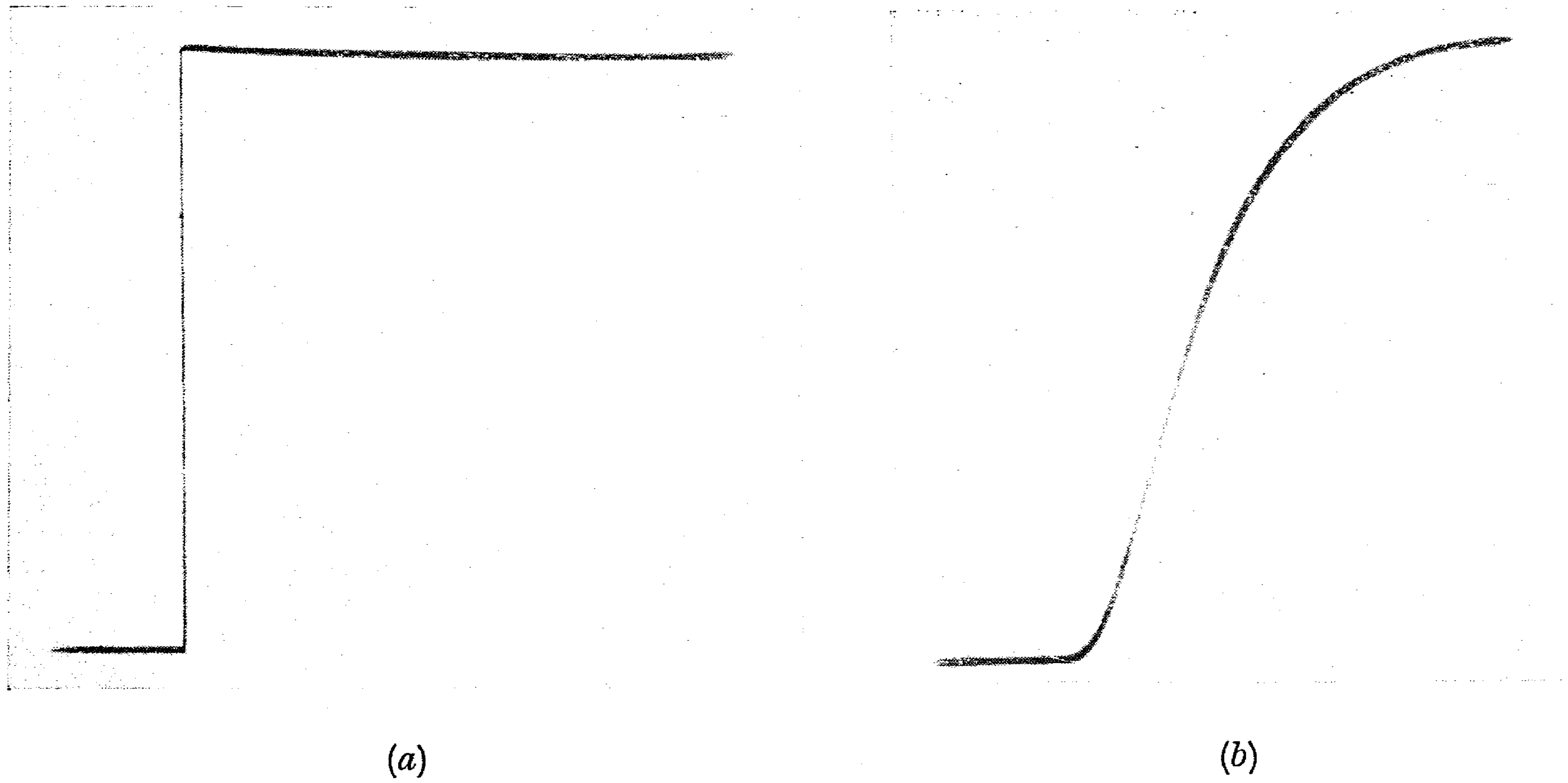


Fig. 16.—Experimental verification of high-frequency response to Heaviside transient.
(a) Transient. (b) Response.

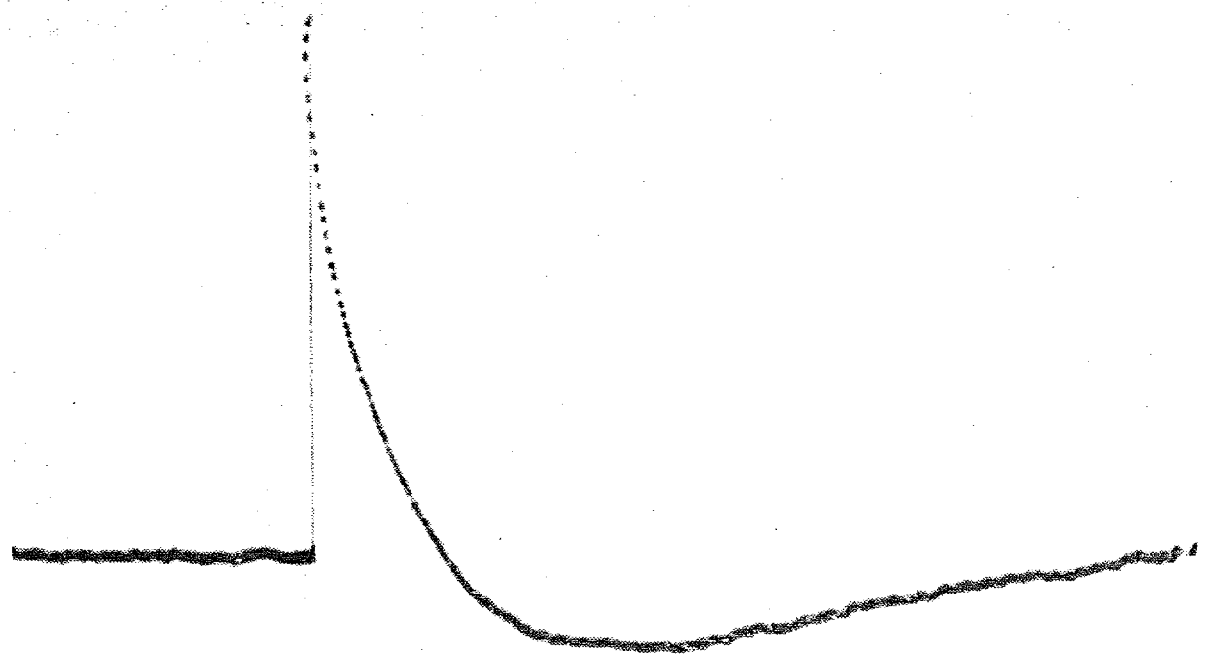


Fig. 17.—Experimental verification of low-frequency response to Heaviside transient.

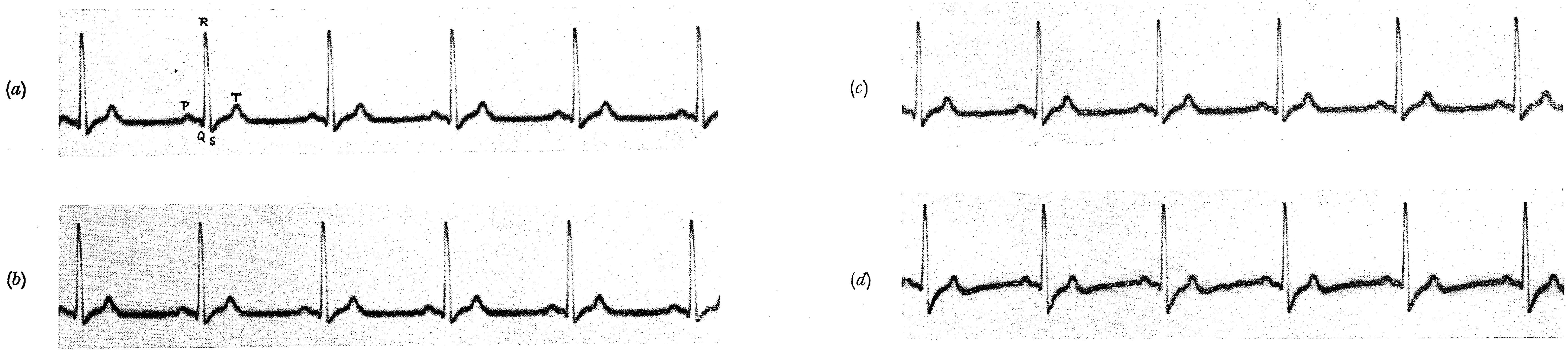


Fig. 18.—Effect of varying intercoupling time-constant of amplifier.
(a) Control. (b) $RC = 8$ sec. (c) $RC = 4$ sec. (d) $RC = 0{\cdot}5$ sec.

Plate 3

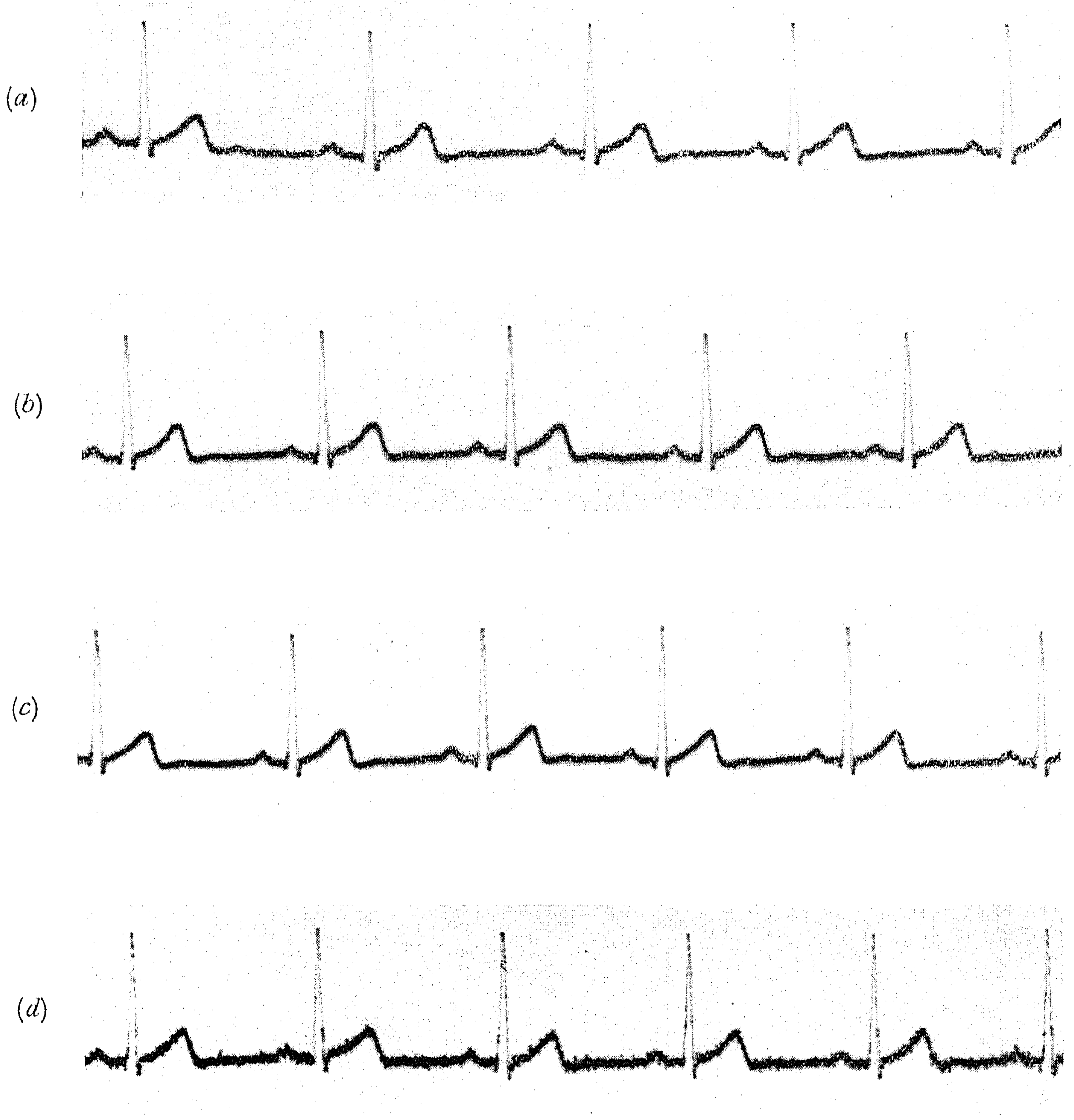


Fig. 19.—Effect of alteration of filter-circuit time-constants.
(*a*) 0·002 sec. (*b*) 0·001 sec. (*c*) 0·0005 sec. (*d*) " Strays " only.

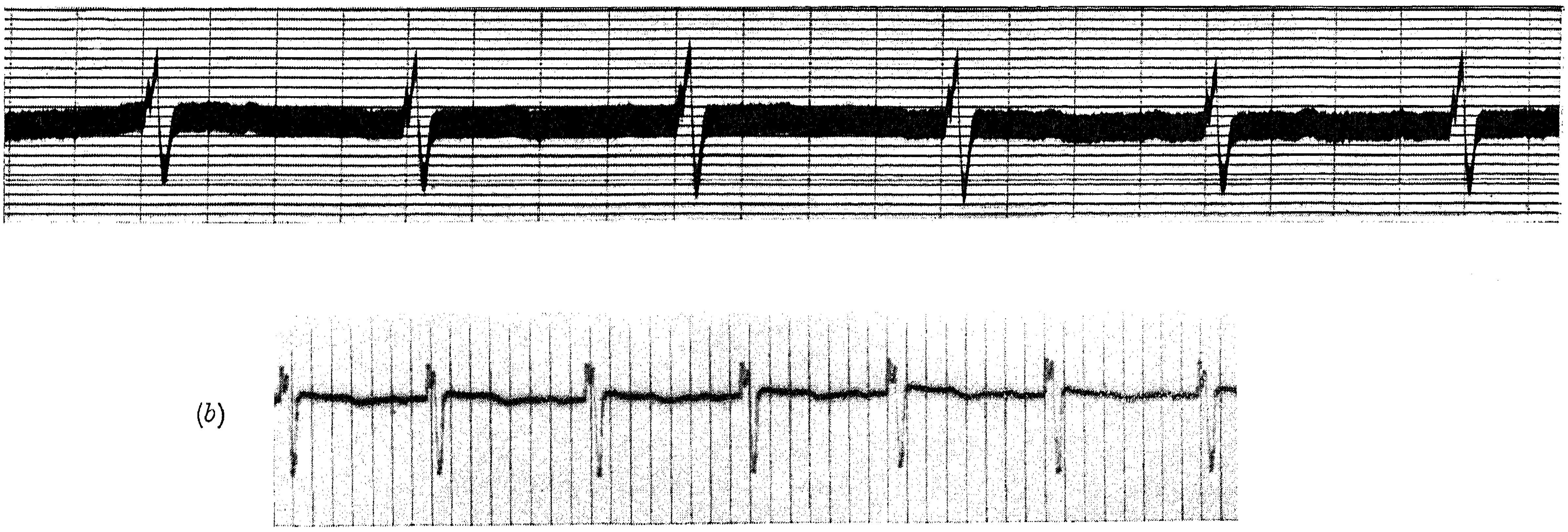
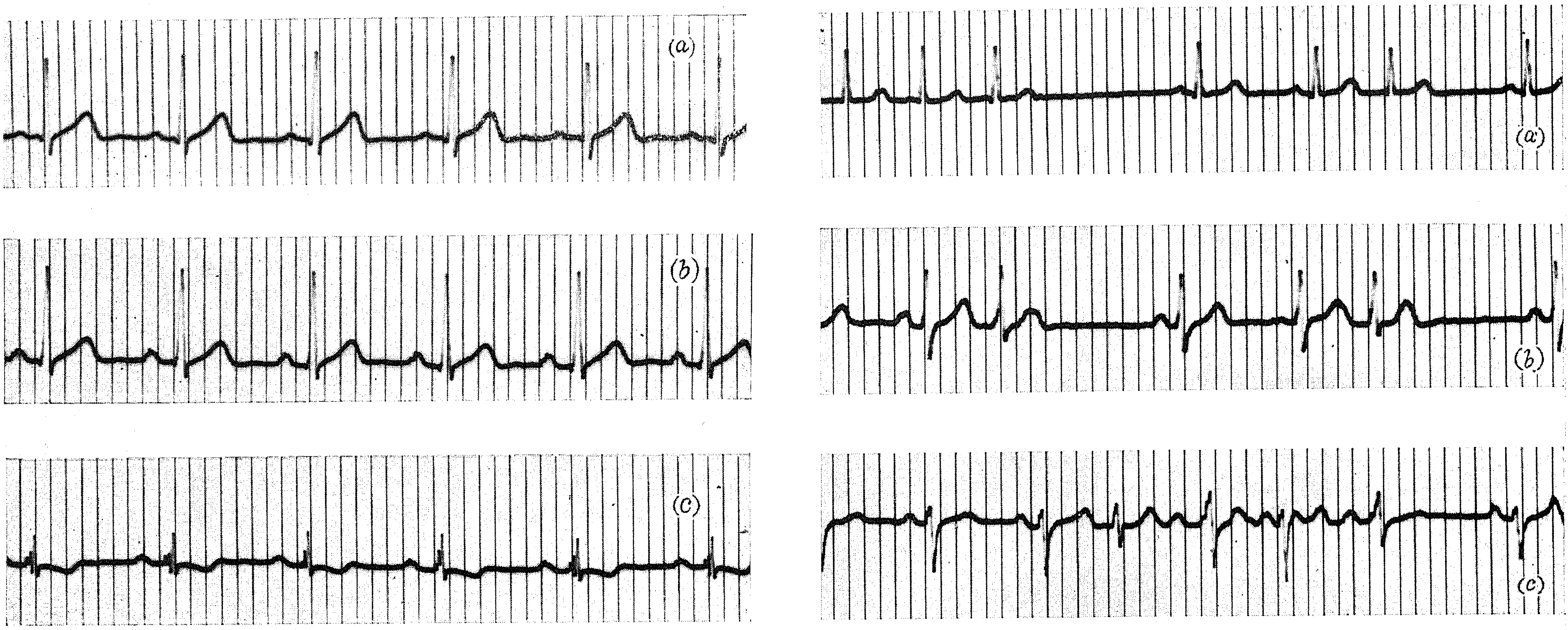


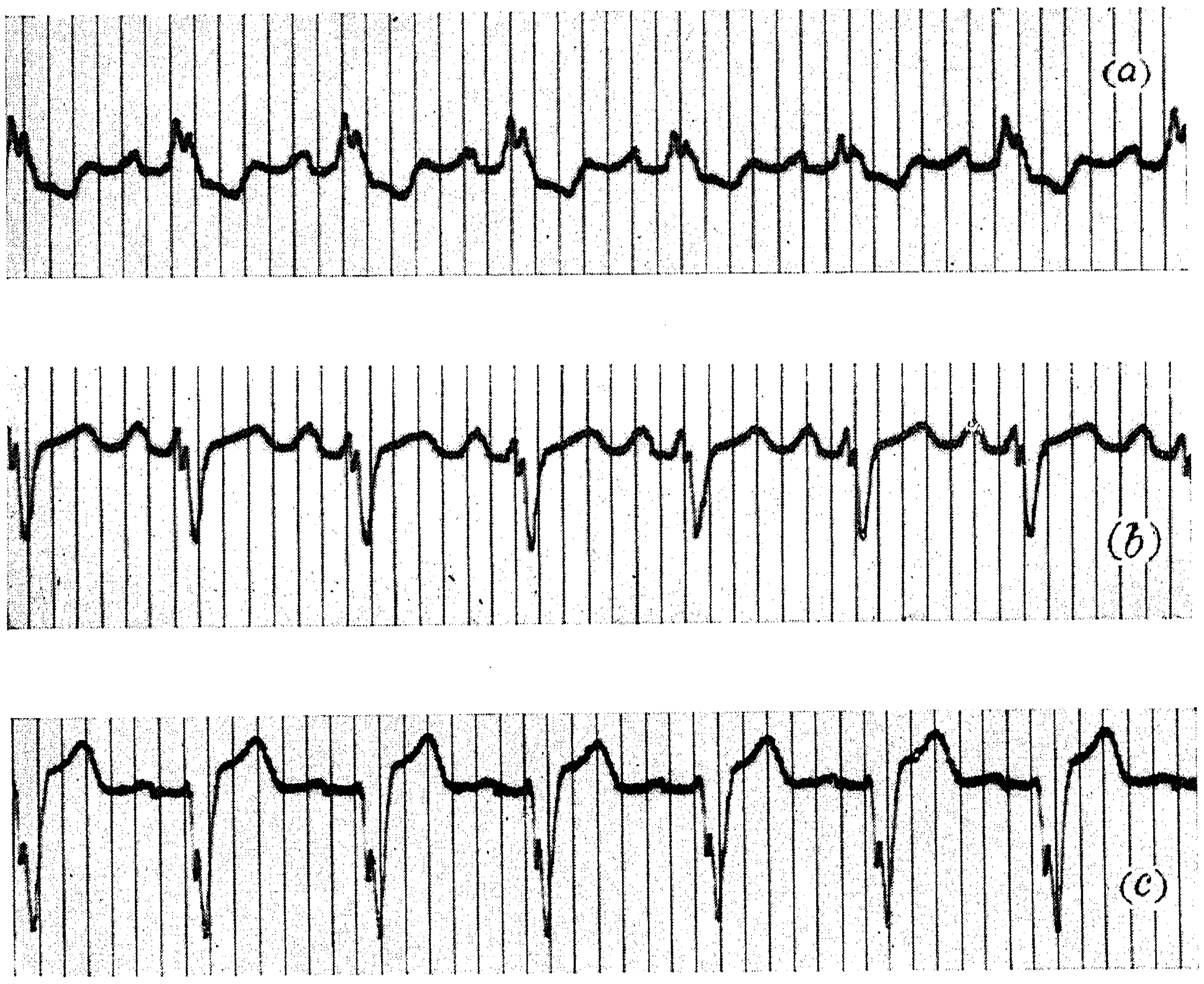
Fig. 20
(*a*) String-galvanometer record.
(*b*) Cathode-ray oscillograph record.

Plate 4



A. Normal
(a.c. mains, patient sitting).

B. Nodal extrasystole (multiple)
(rotary convertor driven from motor-car battery, patient recumbent).



C. Left Bundle-branch Block
(a.c. mains, patient sitting).

Fig. 21.—Representative electrocardiograms in the three leads.
(*a*) Lead I. (*b*) Lead II. (*c*) Lead III.

shown, which are a fair average of those now obtained, cannot be criticized for their lack of clarity (see Fig. 21, Plate 4).

ACKNOWLEDGMENTS

The author wishes to record his gratitude to those members of the staff of Messrs. A. C. Cossor, Ltd., who have made this work possible; particularly to Mr. L. H. Bedford, Dr. F. Postlethwaite,[*] and Mr. C. Brookes-Smith, all of whom have given, from time to time, very valuable advice and criticism. The author was privileged to be associated with Mr. Bedford in the design of the original cardiograph, and is at the present time collaborating with Mr. Brookes-Smith in a redesign of the current model.

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DISCUSSION BEFORE THE INSTITUTION, 8TH APRIL, 1937

Dr. T. F. Cotton: The most exact data that we possess of heart disease are those recorded by the electrocardiograph, from which has also come our knowledge of the mechanism of the heart beat. The Cambridge type of electrocardiograph is accepted all over the world as reliable in the laboratory and at the bedside. The introduction of the portable instrument has proved of the greatest value to us clinicians. I have had my instrument for 8–9 years, and it has proved satisfactory. It is true that I have broken strings at inconvenient moments, and that in many houses I have been unable to take records because of electrical interference. I have also sometimes wanted to see the electrocardiogram while it was being recorded at the bedside. The mirror-galvanometer instrument has an advantage in that there are no strings to break. The time taken to make a record is about the same whether the string or the mirror-galvanometer instrument is employed. Neither allows us to see the electrocardiogram when it is being recorded.

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[*] During the time that he was attached to their Research Department.

The Cambridge and mirror-galvanometer instruments meet the requirements of the hospital, but in private practice it is an advantage to know what the electrocardiogram looks like before one leaves the patient's house.

The chief merit of the cathode-ray oscillograph, apart from its reliability and indestructibility, is the fluorescent screen and the long afterglow of the latter. The visual impression lasts long enough for one to recognize the essential features in the curve, and this is important. An instrument of the type described in the paper has been in use at the National Heart Hospital for 2 years, and it is satisfactory. I have also seen it employed in the country at the bedside, where it meets all the requirements of the complete electrocardiographic examination.

Finally, with regard to the fourth lead, this is now being used more widely and we find it sometimes gives information which the other leads do not. In 10 to 15 per cent of a group of patients with coronary disease we can get signs of the disease from the fourth lead which we cannot get from the other standard leads. I understand that the instrument makers anticipate that a record from the fourth lead will in the future always be insisted upon in the taking of electrocardiograms. This will mean four slits instead of three, and perhaps a wider camera.

Mr. R. S. Whipple: As the author refers so frequently to Prof. Einthoven and to the records obtained with the string galvanometer, I feel that he regards these records as standards against which the results obtained with the cathode-ray oscillograph should be compared. In this I think he is correct, especially if the comparison is made with the original Einthoven records. Einthoven himself was a master of fine technique, and always aimed at a high standard of perfection. In this connection it is of interest to refer to a record reproduced in a paper by Einthoven which was published in 1903.* In this paper, which deals with the galvanometric recording of the human electrocardiogram, the time scale is 25 mm. to the second, and this was the time scale that Einthoven wished to make standard practice for the electrocardiograph. The scale was drawn by a beam of light which was passed through a cylindrical lens, the light being allowed to fall upon a photographic plate at $\frac{1}{25}$-sec. intervals by means of slots cut in a rotating disc, driven by a phonic motor. A broader beam of light was allowed to fall every $\frac{1}{5}$ sec. by means of wider slots placed at correct intervals upon the disc. I remember Einthoven taking an ivory scale, divided in millimetres, from his pocket and measuring a record to show how accurately he was obtaining the desired time-scale. He was not wedded to this particular time-scale, because in another paper published in 1903,† discussing the use of the galvanometer for general physical work, he included records in which 1 mm. corresponds to 0·1, 0·01, and 0·004 sec., respectively.

I think that the author will agree with me that it is not advisable to standardize too rigidly on any one time scale. I prefer 25 mm. to the second, rather than 20 mm., because it has become the general cardiographic practice. On the other hand, for abnormal hearts the time scale must be capable of variation. For example, a scale which is suitable for a heart beating at 30 per minute is not the best for one beating 6 times as fast.

There is little doubt that the greater part of the trouble experienced by the users of the electrocardiograph in the past has been due to the difficulty of rendering the quartz or glass fibre conducting. Einthoven chemically deposited a film of silver on to the fibre and, after doing so, used to polish it to render the film more homogeneous and smooth. He did this most skilfully, but the instrument maker frequently experienced great difficulty in doing so. For many years this difficulty has been overcome by bombarding the fibres with cathode rays, using gold electrodes. Molecules of gold are projected at a high velocity on to the fibre, and key themselves into the body of the fibre. Thus a modern fibre rarely becomes non-conducting.

An improvement that has greatly reduced the weight of a cardiograph outfit is the introduction of permanent magnets made of high-retentivity steel in place of the electromagnet. The permanent magnet has also eliminated the change in sensitivity of the instrument owing to the slow heating-up of the electromagnet of the galvanometer due to the current in the coils and hence the change in the tension of the moving system. This improvement has eliminated a great source of worry to the cardiologist.

With regard to the question of non-polarizable electrodes, I think it is no exaggeration to say that the cotton-wool pads soaked in strong salt solution, and also the forms of non-polarizable electrodes containing saline solution, are practically obsolete. Metal electrodes with Cambridge jelly are now in general use, and any one who has used this combination will appreciate how it has eliminated the difficulties of the old technique.

Referring to Fig. 6, I am at a loss to understand how the author obtained a record showing such an extreme amount of somatic muscle action. It would be interesting to know the circumstances under which this record was obtained. A few months ago Dr. H. B. Russell published a paper* dealing with the electrode jelly, and stated that somatic muscle action was much less apparent when this preparation with a metal electrode was used, in place of the non-polarizable pot electrodes.

I am not sure what value the medical man will place on the fleeting visible records: that they are beautiful and, for teaching purposes, instructive, I have no doubt, but experience only will show how useful they are in diagnostic work. I gather that when a patient is undergoing treatment it may be necessary to compare the photographic records taken at the beginning and during the treatment, and it is on these records that the doctor is largely able to decide the progress of the patient. Accurate measurement of time-intervals is also of first importance, and this can only be obtained from reliable photographs.

Prof. E. W. Marchant: I am especially interested in this paper because about 5 years ago we designed in our laboratories a portable cardiograph on rather different lines from the author's instrument. Instead of using the cathode-ray oscillograph we used a much less sensitive form of string galvanometer, and, in order to get a sensible deflection for the small voltages which were obtained from the heart, a valve amplifier was employed to amplify the signals. The records we obtained, of course, were similar to those given by the ordinary string galvanometer. The advantage of using our type of apparatus was that, owing to the greater thickness of string, the magnification which was needed in order to get a record was not so high, and therefore the amount of light which was wanted was not so great as is needed with the ordinary string galvanometer. The mass of the string was much greater than in the Einthoven instrument, and the sensitivity was very much less. The air damping of the string, of course, was not so effective: this drawback was overcome by using oil damping. We obtained close agreement between the records given by this instrument and those provided by the ordinary Einthoven cardiograph.

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* *Archives Néerlandaises des Sciences Exactes et Naturelles*, 1903, vol. 9, p. 202.

† *Annalen der Physik*, 1903, vol. 12, p. 1059.

* *The Lancet*, 23rd November, 1935.

The point which has a close relation with the present paper is that we had to design an amplifier which would give exact correspondence between the voltage of the incoming signal and the outgoing current from the last valve. The difference between this requirement and the one for the cathode-ray oscillograph is, of course, that in the latter there must be exact correspondence between the voltage which is put into the first stage of the amplifier and the voltage on the last stage. But it is comparatively easy to get as close agreement in the one case as in the other.

The author's instrument has the great advantage that it gives a visible record which can be examined at the patient's bedside. In the instrument which I have been describing the record was obtained on a photographic film. On the other hand, in the author's instrument the voltage needed is of the order of 800 volts, and I presume that this offers some difficulties in connection with the design of portable instruments.

One of the great advantages which the cardiograph with an amplifier has over the direct-reading type of instrument is that with difficult patients the former makes it much easier to get a good record, because the variations in the skin effect are comparatively slow, and do not come through on the record to the same extent as do the actual cardiograms.

I think that Fig. 15 is not quite complete. There is a lower part of the scale which seems to have no curve attached to it.

Mr. C. Bowden: I should like to make one or two criticisms of the author's amplifier circuits. On page 498 it is stated " Unfortunately some of these instruments have been constructed with valve amplifying circuits which were by no means free from distortion. . . ." Fig. 16(*a*) (Plate 2) shows a Heaviside transient, and Fig. 16(*b*) gives the corresponding response of the amplifier. From the oscillograms it is clear that the original transient is by no means reproduced free from distortion. The distortion is entirely due to the time-constant of the current resulting from the capacitance-coupled circuit. What I think is the only practical solution of the problem is to use a direct-coupled amplifier which has an infinitely long time-constant; so that, if one injects into the input circuit of the amplifier an instantaneous impulse which is maintained for a definite period at a constant value, that impulse is reproduced in the amplifier in almost exactly the same form. The degree to which exact reproduction of low frequencies or slow transients can be obtained by an amplifier which is directly coupled is very much greater than that with an amplifier the stages of which are connected by condensers of finite capacitance.

Owing to the high magnification of the valves used in the author's amplifier, and the high value of the anode resistance which must be employed to obtain the high gain per stage necessary, the straight portion of the operating curve of the first valve is extremely small, and therefore any variation of grid potential due to the patient or the electrodes (which may have a value as great as 30 millivolts) must necessarily move the operating point of the valve on that curve. In a capacitance-coupled amplifier this is evidenced by the complete paralysing of the amplifier when the patient is switched on to one of the leads. The coupling condensers, however, rapidly discharge themselves and adjust themselves to a new set of values, and the oscillograph goes on working, but not under the conditions under which it was working when it was calibrated. If a direct-coupled amplifier is used, unless the grids of all the valves are at exactly the same potential as they were when it was calibrated the light spot will be displaced on the screen; and the readjustment of the light spot automatically restores the amplifier to its original condition, so that with such an amplifier not only does one obtain the certainty of a perfect low-frequency or maintained transient response curve but also one is certain that the amplifier is operating on exactly the same point of its curve as it was when it was calibrated. The disadvantage of a direct-coupled amplifier is that it must be reset for each connection to the patient; but this can very easily and rapidly be done by a grid-voltage potentiometer in the first valve circuit.

A point in favour of an amplifier of this type is that if the characteristic of any valve, resistance, or battery becomes altered beyond reasonable limits the effect is immediately shown by the amplifier refusing to work. With regard to the conventional frequency characteristic of the amplifier, I think it is best completely to ignore this so far as electrocardiography is concerned, because the subject deals with transients which are unrepeated, and therefore the usual filter calculations do not apply.

The author mentions that he makes use of cathode rays because of their extremely low inertia; but a filter which cuts off at 400 cycles per sec. is incorporated in the amplifier circuit and this in my opinion completely offsets any advantage arising from the low inertia of cathode rays.

Finally, with regard to electrical interference, my experiments show that the interference is electrostatic and not electromagnetic in character. Very often less interference is observed when the electrical apparatus in the patient's house is switched on than when it is switched off. This is probably due to the fact that the alternating potential gradient in various parts of the room is lowered owing to parts of the circuit being in direct connection.

Mr. S. L. Barron: I should like to inform Dr. Evans that long electrocardiograph records can be obtained with any form of galvanometer equipment, or oscillograph equipment, by using the right form of camera.

Prof. Marchant spoke about the instability of the skin resistance giving him trouble when he was working on his machine. This effect does not give trouble nowadays, because the stability of the resistance of the patient has been much improved by the electrode jelly which is now used. This stabilizes the resistance of the patient to such a remarkable degree that if one is taking Lead I the patient can get up and walk about very slowly, and still one gets no deviation from the zero of the electrocardiogram.

The frequency characteristic of the author's amplifier is exceptionally good, and I feel that it is essential to the success of his instrument.

Mr. F. R. W. Strafford: I should like to ask one question with regard to the diagnosis of certain complaints by means of the cardiograph. If the patient is very nervous and is fully aware, or thinks he is aware, of his symptoms, will the change in the rate of the heart beat occasioned by his nervousness result in false evidence being recorded on the electrocardiogram?

Dr. K. Machell Ward (*communicated*): The cathode-ray electrocardiograph described in the paper is capable of a degree of precision which has hitherto been lacking in this field of diagnostics. One has only to compare the records reproduced in Figs. 20(*a*) and 20(*b*) to realize the advantage in sensitivity and freedom from distortion which the author's cardiograph has over the Einthoven string-galvonometer type. It is not many years since this was the only form available for ordinary clinical use, and I well remember the mistakes in diagnosis into which it led me on many occasions as a student at the Royal Infirmary, Liverpool. A good deal of time was lost through the necessity of seating the patient in a bath, and the diagnosis could not be completed until the plates had been developed, which meant further delay. The use of Cambridge electrode jelly obviates the first of these difficulties, and the author's arrangement permitting visual observation of the record at the patient's bedside removes the second. Further, with the recent advances in photographic technique greatly improved records of a permanent character should be obtainable. Such a record is shown in Fig. 21.

There are one or two detail points of criticism of the paper to which I would draw attention.

With reference to Fig. 1, it should perhaps be made clear to the non-medical reader that the "base" of the heart is the upper and the "apex" the lower extremity.

I notice that the author uses the expression "d.c. amplifier." Does this mean "direct-coupled amplifier," in contrast to the "resistance-capacitance-coupled amplifier"? It would be as well to make this point clear in the final version of the paper,* as, to the electrical engineer, "d.c." invariably means "direct current."

On page 505 the author mentions that the cathode-ray tube circuits are supplied from a rotary convertor driven off the motor-car battery. No part of the modern car is so overworked as the storage battery, and to put further burdens upon it is, I suggest, to ask for trouble. Greater reliability of the portable electrocardiograph would be secured if the rotary convertor were driven direct from the car dynamo, suitable smoothing arrangements being provided in the output circuit of the latter. An alternative would be to install a separate high-voltage d.c. generator gear-driven from the engine of the car.

It would be most interesting to have some further information as to the means of avoiding distortion of the records by magnetic interference. This difficulty presumably is of importance where (as is frequently the case) the apparatus has necessarily to be operated in the neighbourhood of circuits supplying lifts, X-ray apparatus, and electromedical appliances of various sorts which are in constant use.

In conclusion, I should like to mention the extraordinarily good correlation between the amplifier response curves recorded in Figs. 16 and 17 and the theoretical values plotted in Figs. 14 and 15. The efficiency of the amplifier is further confirmed by its performance when supplied from the simple but ingenious "artificial patient." No doubt this device is valuable for testing purposes in the commercial production of the electrocardiograph.

Dr. William Evans also took part in the discussion, and showed a series of lantern slides indicating the application of electrocardiography to clinical medicine.

Dr. Douglas Robertson (*in reply*): I should like to thank all those who have been good enough to come to-night to take part in this discussion—particularly Dr. Cotton—and I am grateful for this opportunity of being able to make some sort of public acknowledgment to him for his stimulating interest and encouragement to me in this work. I am happy in knowing that he, with me, sees the inherent advantages of the cathode-ray electrocardiograph, in particular that of immediate visual observation of the electrocardiogram at the bedside, for as long a period as is required and without the necessity of waiting for the processing of photographic material.

I am, of course, entirely in agreement with Mr. Whipple as to the very great importance of serial electrocardiograms taken at successive examinations of the patient (especially in cases of doubtful coronary disease), but that surely does not detract from the advantage of having immediately visible records. I have, so far, three years' experience of this in cardiological practice and I can assure Mr. Whipple that there are not many details of the electrocardiographic curves which escape one's notice during this first visual impression—even the presence of a lengthened P–R interval becomes quite obvious after very little practice. I would even go further and say that one can in some cases get a better idea of the electrocardiogram by watching it for a time, especially where an electrocardiographic event happens fairly infrequently, than one can by inspecting a length of record representing only 3 to 4 seconds. For example, it is sometimes desirable to know where, in the cardiac musculature, infrequent premature beats originate, and if these occur seldom or in infrequent bursts they may be missed in a short length of record.

It is true, as Mr. Barron says, that long lengths of record may be taken with the modern paper-roll camera, but I am sure he will agree that the taking of long lengths of record has disadvantages as regards both cost and trouble in development. It will be realized, of course, that the cathode-ray electrocardiograph allows equal facilities in the taking of long records if these are really required.

Dr. Cotton has mentioned the growing importance of

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* This has been done for the *Journal*.

Lead IV in cases of coronary infarction. I am inclined to think, however, that one of the other chest leads may be more universally adopted than Lead IV, since that has the great practical disadvantage that it is necessary to move a very ill patient for the application of the back electrode. I refer to the left leg—praecordium lead (of Wolferth and Wood) and the right arm—praecordium lead (of Roth), both of which give similar information to that given by Lead IV.* Dr. H. Nielsen† informs me, in a personal communication, that he is now using the right arm—praecordium lead more and more, especially in cases of recent coronary infarction, and that he uses the praecordial electrode as a wandering or searching electrode. He has been able to get localizing (electrocardiographic) signs in this way, which suggests that this method may become of great value in locating the site of a coronary infarct. As Dr. Cotton observes, it will become increasingly important to provide a fourth camera slit when using the present string-galvanometer photographic technique. Where the leads are recorded consecutively (on photographic strips) as in the cardiograph, this of course does not apply, but it may be an advantage to provide another electrode adapted to chest application, and a fourth position on the lead-selector switch.

Mr. Whipple is quite correct in his assumption that I have treated string-galvanometer records as standards for my comparisons. It is upon the string galvanometer that, for more than 30 years, the whole of the science of electrocardiography has been built, and it is very much to the credit of the instrument manufacturers that an instrument with so many inherent drawbacks has rendered such yeoman service to cardiologists during all this time. But I am quite convinced that Einthoven, were he alive to-day, would have been the first to exploit the possibilities of the thermionic amplifier and cathode-ray tube in this field—developments that have come only in comparatively recent years.

I am not at all sure that I agree with Mr. Whipple about the non-standardization of the time scale. My point is really this, that it is easier, in the end, for cardiologists to get used to one time scale whatever the heart rate may be (incidentally Mr. Whipple's extremes of pulse rate are overstated—a ventricular rate of less than 40 or of more than 140 is extremely rare), for then the performance of a heart from the cardiographic point of view is evident immediately, and—as I stated in the substance of the paper—inferences from the actual shape of the curve may be made with reasonable confidence. What I particularly wished to stress was that cathode-ray electrocardiograms, with their thinner base-line, making a clearer record, allow the adoption of a standard time scale without any loss of clarity (cf. Figs. 20(*a*) and 20(*b*), Plate 3). But the question is one which must be decided by practising cardiologists. Personally I always work with a time scale of 2 cm. per sec., and am now thoroughly accustomed to that; I find it a little irksome to have to estimate and measure up electrocardiograms conforming to other time scales—but I fully realize that this is a matter of personal idiosyncrasy and habit.

I must apologize to Mr. Whipple for Fig. 6 (Plate 1). It was inserted to give a non-medical audience some idea of the extent to which somatic-muscle action-potentials may interfere with the electrocardiogram; it was actually caused by shivering of the subject.

I wish to thank Prof. Marchant for coming from Liverpool to take part in this discussion, and I feel I owe him an apology for not having mentioned his electrocardiograph in the text of the paper. In answer to the two points he has raised, we have had no difficulty, as regards portability, in designing a suitable a.c. eliminator to give 800 volts, since the current required is only 5 or 6 milliamps. The problem for direct current is not quite so easy; I will consider some aspects of it in answering Dr. Machell Ward. I must apologize for the fact that Fig. 15 is not quite clear. It is actually complete, and is meant to show that after 2·4 sec. (where £ in Bedford and Puckle's formula is 0·6) the voltage response of the amplifier becomes negative, only becoming slightly positive again at 13 sec. What is really happening is that there is a slow oscillation very greatly damped —the damping being negatively exponential in time.

Mr. Bowden has brought forward many interesting points of great importance; since, however, nearly all of these have already been answered in the substance of the paper, I do not propose to reiterate their discussion here. There is, however, one point which he has raised that has certainly not been dealt with adequately and which requires amplification. It is the matter discussed in the second paragraph of his remarks and in the 4th paragraph of Section (5.1) of the paper. It is certainly true that, although the grid-swing of the first valve of the amplifier is extremely small, nevertheless variations in skin potentials will determine a different working point on the grid-voltage/anode-current characteristic, and therefore, as he rightly says, the amplifier may perform differently when connected to the patient, as compared with its performance during calibration. I had thought it best to settle this matter by direct experiment, and the curves of Fig. A show the results obtained, using, of course, a real patient. It will be seen that there is practically no difference between them, and that therefore this possible source of error in the resistance-capacitance-coupled amplifier does not give rise to any distortion in actual practice.

The question of interference from alternating-current sources perhaps requires more detailed consideration. Experiment shows that the interfering voltage is picked up to a small extent by the apparatus but mostly by the patient, and that this pick-up occurs partly electrostatically by the capacitance effect of the patient in the electric field (this is the "reactive component" of the interfering voltage), and partly electrodynamically by the actual ohmic flow of current to the patient and apparatus by leakage paths from the source of interference (this is the "resistive component" of the interfering voltage). The interfering voltage may therefore be represented by the vector diagram of Fig. B, and the task of the neutralizing circuit of Fig. 11 is to oppose each component of the interfering voltage (as also indicated in Fig. B) in such a way that the resultant vector of the interfering voltage is exactly opposed by a resultant vector from the neutralizing circuit which is equal in length and exactly 180° out of phase (a voltage, in other words, " equal in amplitude and opposite in phase "—to quote from the paper). The frequency of the neutralizing alternating voltage looks after itself, since the neutralizing circuit is fed from the same a.c. source as that which produces the interfering voltage.

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* The matter is succinctly discussed in Carter's book: *The Fundamentals of Electrocardiographic Interpretation* (Ballière, Tindall, and Cox, London, 1937), chap. 23.

† See Reference (16).

I can assure Mr. Barron and Mr. Whipple that I am not unmindful of the excellent electrical properties of Cambridge electrode jelly, but we have found, in practice, that simple pads soaked in strong saline are equally effective (with the high input impedance of the cardiograph), and they have advantages in being less distasteful to the patient, and in simplicity of construction and application.

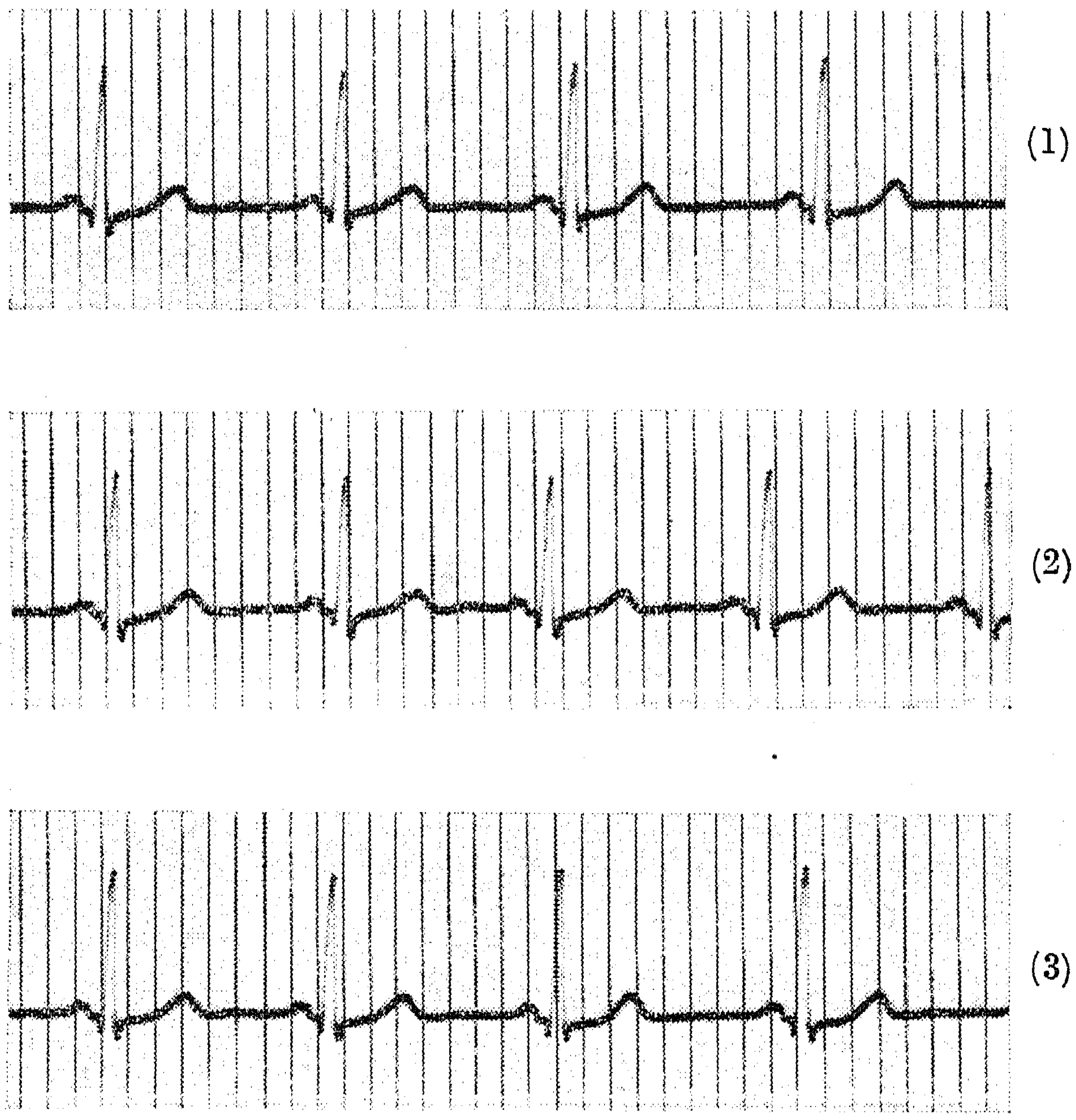

Fig. A.—Normal, Lead I, using saline pads.

(1) No bias (usual arrangement).
(2) First valve biased 100 mV negative, through the patient.
(3) First valve biased 100 mV positive, through the patient.

Replying to Mr. Strafford, all doctors, cardiologists included, are fully alive to the nervous elements in their patients, and are trained to discount such factors in assessing the physical condition. A patient who is nervous will usually have a more rapid pulse, and probably be conscious of his heart beating, but the essential appearance of the electrocardiogram is not altered thereby. Such nervous patients, though, are often bad subjects in respect of the production of involuntary muscular tremor, which may obscure the finer details of the electrocardiogram.

I am grateful to Dr. Machell Ward for her very kind appreciation. I will reply to her criticisms *seriatim.* I entirely agree about Fig. 1, and about the expression " d.c. amplifier," and I apologize for my lack of clarity in both cases. The satisfactory production of 800 volts from a low-voltage d.c. source is not an easy question. We have used a small rotary convertor which requires only 2 amps. input (and is therefore only a very small drain on the car battery), but although fairly satisfactory it has drawbacks. Future work may reveal a more satisfactory method; perhaps an h.t. vibrator (as used for car radio) may prove better, or it may be found better to use h.t. batteries for completely satisfactory performance, though the renewal cost of these becomes a serious item.

The question of magnetic interference is one that I am afraid I am not able to answer adequately, as I have no great experience of it. In the few experiments that I did with Dr. Russell J. Reynolds, on simultaneous X-ray cinematography (of the heart) and electrocardiography, we had to shield patient and electrocardiograph, with d.c. rotary convertor and batteries included, to avoid interference from the X-ray transformers, etc.—and even here we were more concerned with electrostatic interference than with magnetic interference. But I well remember my first experience of magnetic interference from a lift (at the Radcliffe Infirmary, Oxford) when the movements of the spot became elliptical! However, unless such apparatus is really close, there is no appreciable interference that cannot be obviated by the suitable disposition of electrocardiograph and patient. In my consulting room I am situated immediately above a radiologist; I get no magnetic interference from his apparatus, but there is a momentary jumping of the spot when he switches on and off; this is due, I assume, to variations in load on the main supply—not to any electromagnetic effect.

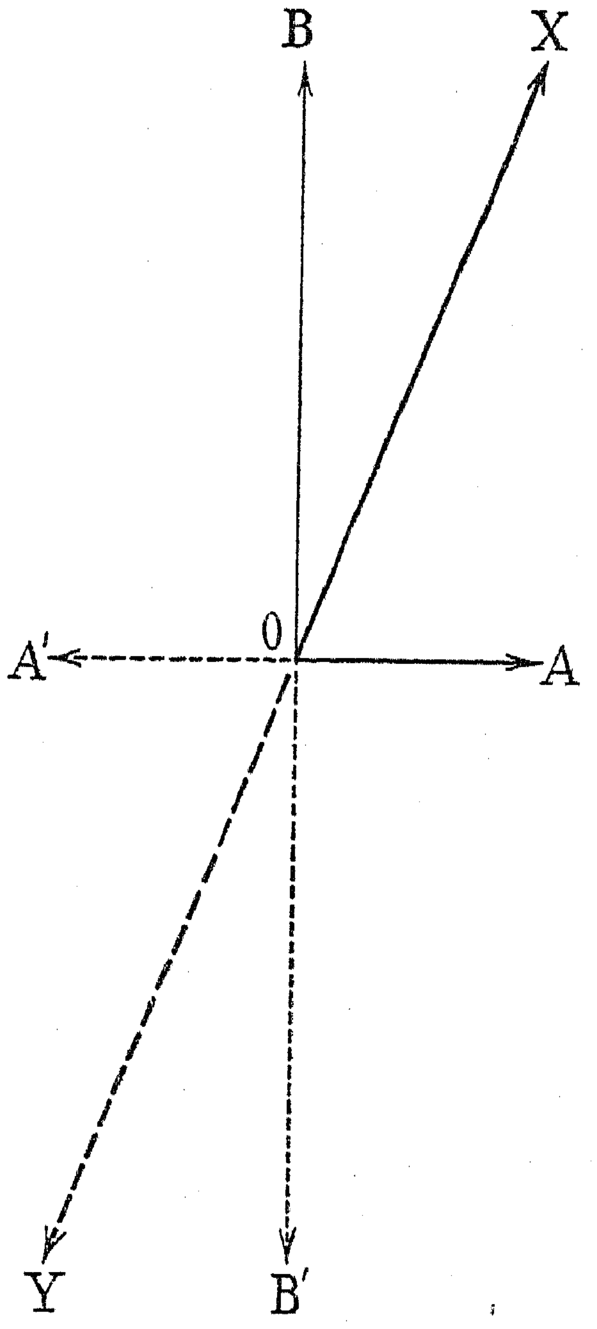

Fig. B

OX = interfering voltage. OA is resistive component and OB is reactive component.
OY = neutralizing voltage. OA' is resistive component and OB' is reactive component.

I am very grateful to Dr. William Evans for supplementing the paper with his excellent symposium of electrocardiographic appearances.

COIN MECHANISMS, WITH PARTICULAR REFERENCE TO ELECTRICITY METERS

By J. PRINCE and M. WHITEHEAD, Associate Members.

(*Paper first received* 28*th August*, 1936, *and in final form* 16*th January*, 1937; *read before the* METER AND INSTRUMENT SECTION 2*nd April*, 1937.)

SUMMARY

The general principles underlying coin mechanisms are considered and analysed, also their relations to coins and tokens. Outstanding historical examples are described, followed by the consideration of some modern applications.

The application of coin mechanisms to electricity meters is dealt with. The influence of tariffs and the reasons and justifications of this method of revenue collection are discussed. Essential points of operation and the conditions of optimum performance are considered.

Finally the paper deals with frauds, foreign practice, and testing, in relation to electricity meters.

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    (2.2). Coins and tokens.
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(1) INTRODUCTION

It is perhaps an obvious point to note that the introduction of the coin mechanism must of necessity have followed the introduction of coins or tokens, and is therefore a development of the coinage system. Coins were known probably before 700 B.C., and the earliest mention of coin mechanisms that the authors have been able to trace dates from about 150 B.C. This gave a measure of holy water. From that time to the present is a big step and we now find an enormous variety of applications.

Some idea of the activity is reflected in the number of patents issued since 1855 for coin-freed mechanisms, as shown in Fig. 1.

Probably the simplest form of coin mechanism, with which is associated the token-freed device, is the coin-freed door of a receptacle. Here the coin merely frees the lock and releases one of a number of piled articles, and the work required for removal is supplied by the individual operating the machine.

Another form is that of the stamp machine where commodity delivery has been rendered automatic. Then we have arrangements such as automatic weighing machines in which many operations are carried out, e.g. indication, audible report, and delivery of printed card.

There is the telephone mechanism, which, although not fully automatic, is capable of receiving a variety of coins.

From this we pass to the single-coin prepayment meter in which the commodity delivered is proportional to the coins inserted and where delivery need not take place immediately or continuously. This form is still further developed into the optional coin meter and the optional-coin fixed-charge meter, where coins of two or three different denominations may be inserted at the discretion of the user. It may, perhaps, be well to note that the general term " prepayment mechanism " which has become so widely used in metering is no longer an appropriate term in view of the introduction of fixed-charge collectors, since in this case there are instances where post-payment as well as prepayment occurs.

(2) GENERAL

(2.1). The General Case

The various functions which any coin-freed device may be expected to perform can be symbolized in a line diagram as shown in Fig. 2.

The first action is that the coin is introduced into the coin aperture. It then passes through a device which tests the coin in order to ascertain whether or not it is of correct denomination. Following acceptance some means of actuating or supplying motion is provided. Then follows a device arranged to facilitate the occasional alteration in the price of the commodity delivered. The next feature is an arrangement for the operation of the differential. This is a mechanism with a threefold function; first, it is actuated in one direction in accordance with the money inserted, secondly, this motion may be counteracted in accordance with the commodity consumed, and thirdly, it controls the commodity supply and indicates debit or credit value. The device arranged to facilitate the alteration in commodity

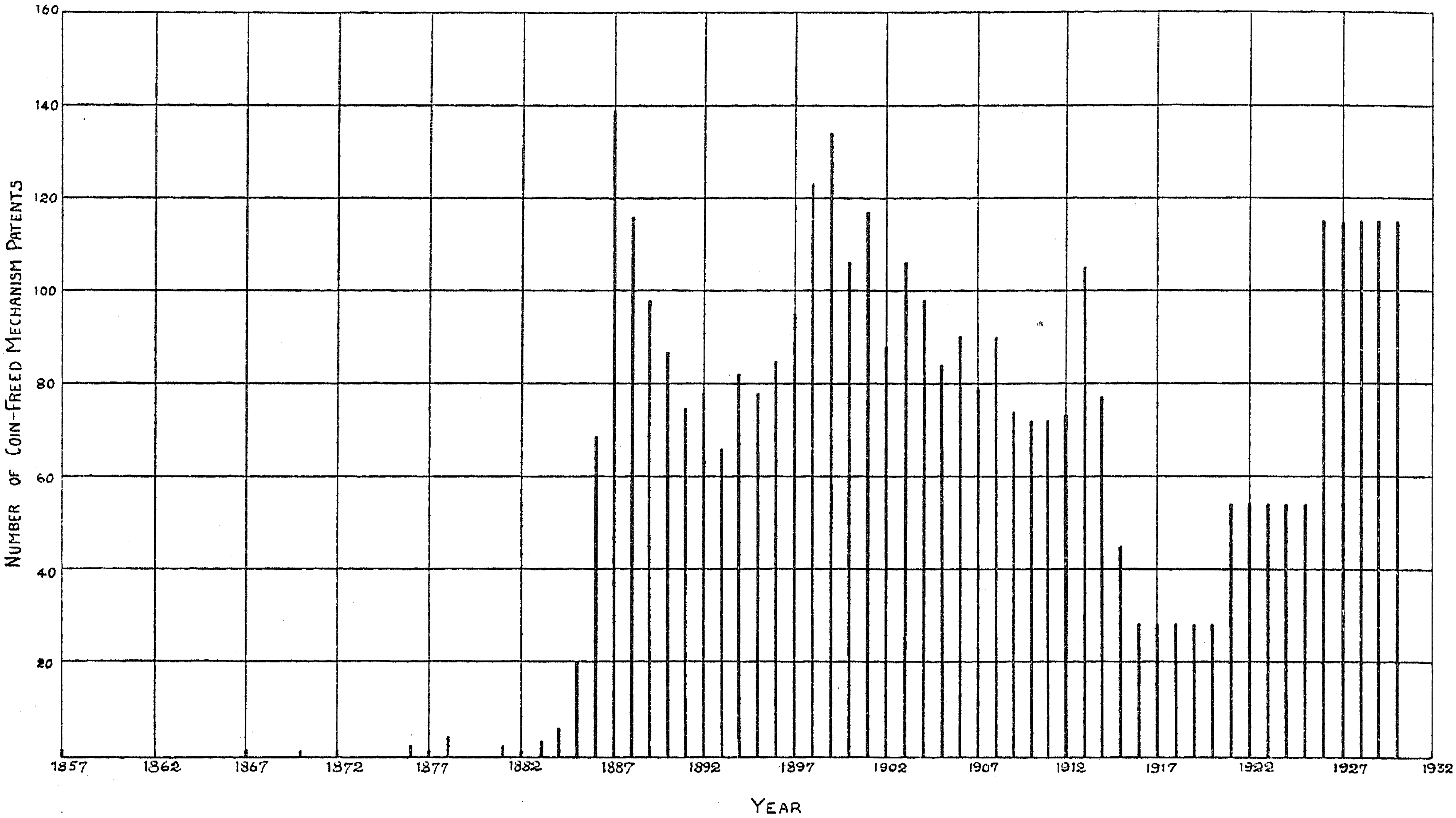

Fig. 1

price may also occur between the commodity-measuring device and the differential.

The functions may be summarized as follows:—

(2.11). Coin receiver.
(2.12). Coin test.
(2.13). Actuation following coin acceptance.
(2.14). Price-change.
(2.15). Differential.
(2.16). Storage.
(2.17). Commodity control.

(2.11). Coin receiver.

In general this consists of an aperture in the frame of the mechanism. It is sometimes fitted with a cover for the purpose of excluding dust. Arrangements may also be made in the case of single-coin mechanisms for the rapid conversion of the size of the coin aperture to suit coins of different value.

(2.12). Coin test.

These may be of the following:—

(*a*) Dimension (diameter and thickness).
(*b*) Weight.
(*c*) Contour (face, edge and holes).
(*d*) Rigidity and elasticity.
(*e*) Material.

(a) Dimension (diameter and thickness).

This test is achieved by the use of callipers which generally take one of three forms. In Fig. 3(*a*) one pair of callipers, often associated with the cover or case of the mechanism, prevents insertion of coins of greater diameter or thickness, followed by another pair of

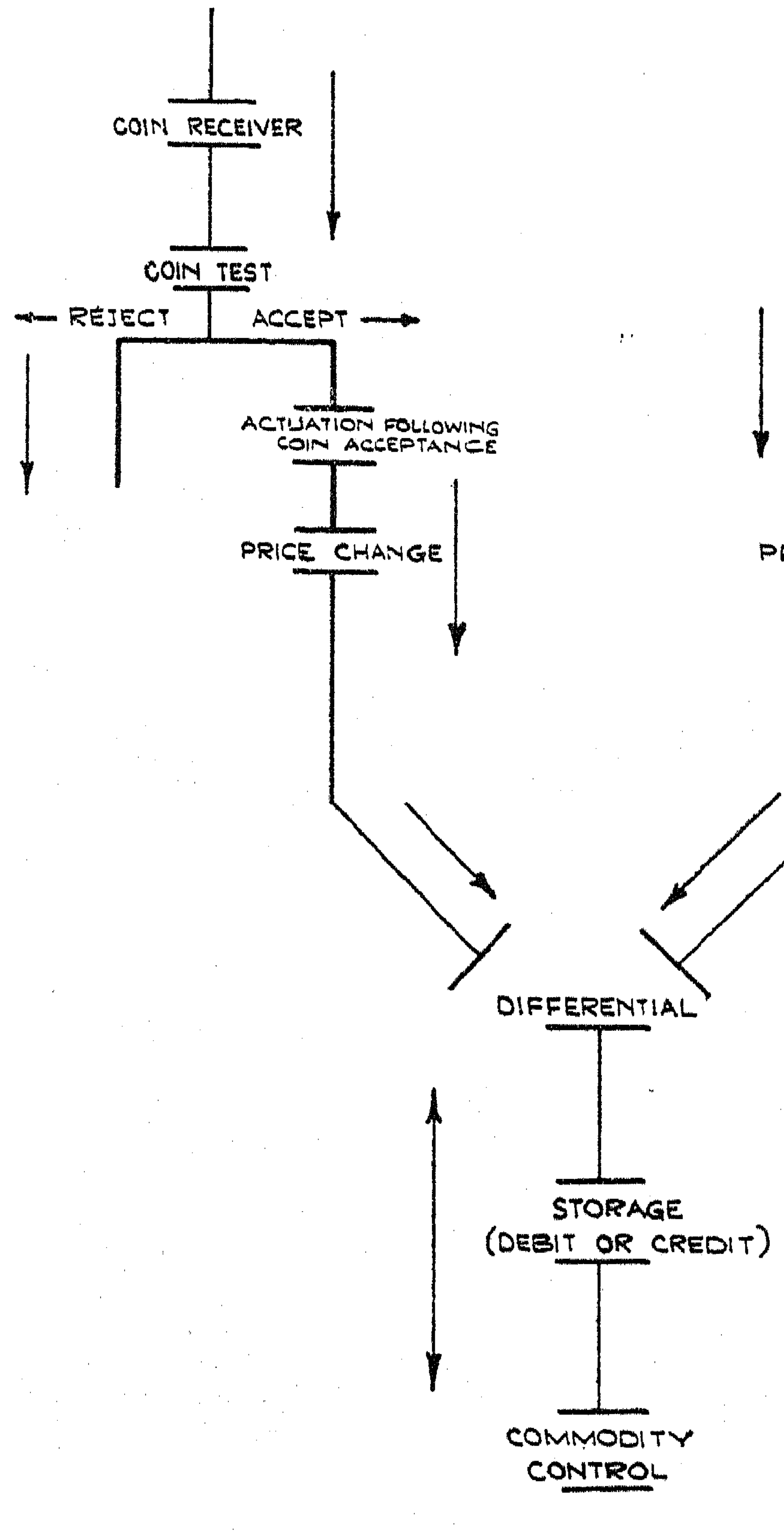

Fig. 2

callipers which allows coins of smaller diameter or thickness to be bypassed. The correct coin is thus retained on two pegs in a position for further operation. Fig. 3(*b*) shows a similar method where no additional operation is required and the coin, if accepted, continues down the runway. An undersized coin in rolling down the runway falls through aperture A, while an oversized coin strikes ridge B and raises lever C and also falls through aperture A. In Fig. 3(*c*) one movable calliper is used, rotation of member A being possible only with the correct coin.

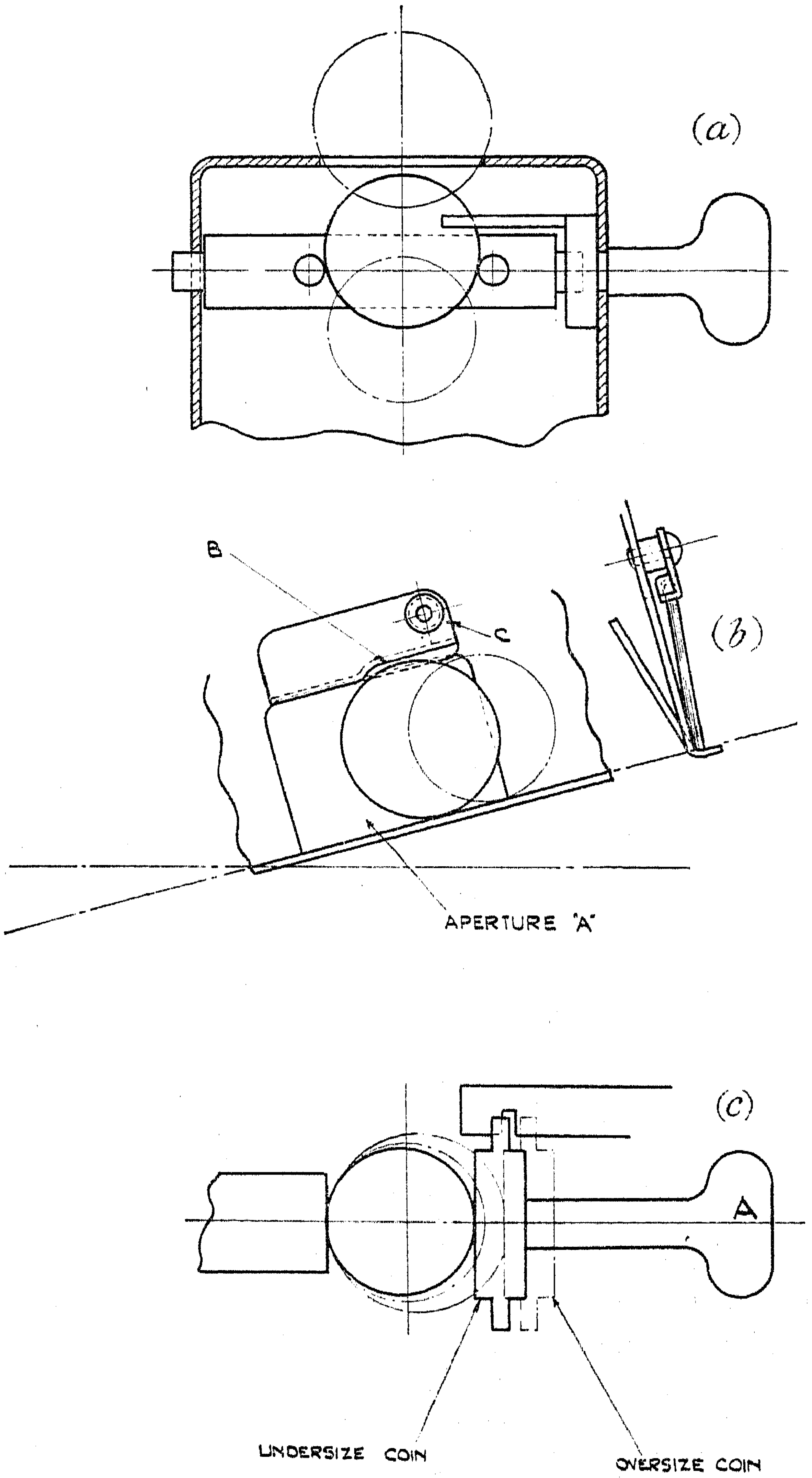

Fig. 3

(*b*) *Weight.*

This is achieved by the use of a pivoted arm or spring; an example is shown in Fig. 4.

Here a correct coin rolls down the chute and depresses spring D sufficiently for the coin to be guided by the rim above and below the reject aperture E. Overweight coins depress the spring too far and the top edge of the coin falls below the top edge of slot E, the coin then overbalancing and falling through the aperture into the reject chute. Underweight coins do not depress spring far enough and the bottom edge of the coin slips through the reject aperture.

(*c*) *Contour.*

Face.

This is typified in Fig. 5(*a*). A coin dropping down chute A has to pass through pivoted feelers B which are mounted to one side of centre-line. Flat coins drop straight through, but coins with contours are momentarily gripped by knife-edges C, allowing coins to swing sideways and strike face E, after which they are deflected into the correct passage.

Edge.

A test for milling may be carried out as shown in Fig. 5(*b*). The milled coin enters a recess in the handle member A. Upon rotation the milled edge of the coin operates a pivoted member B, which in turn is partially rotated. The lower edge C has to miss projection D, which allows complete actuation.

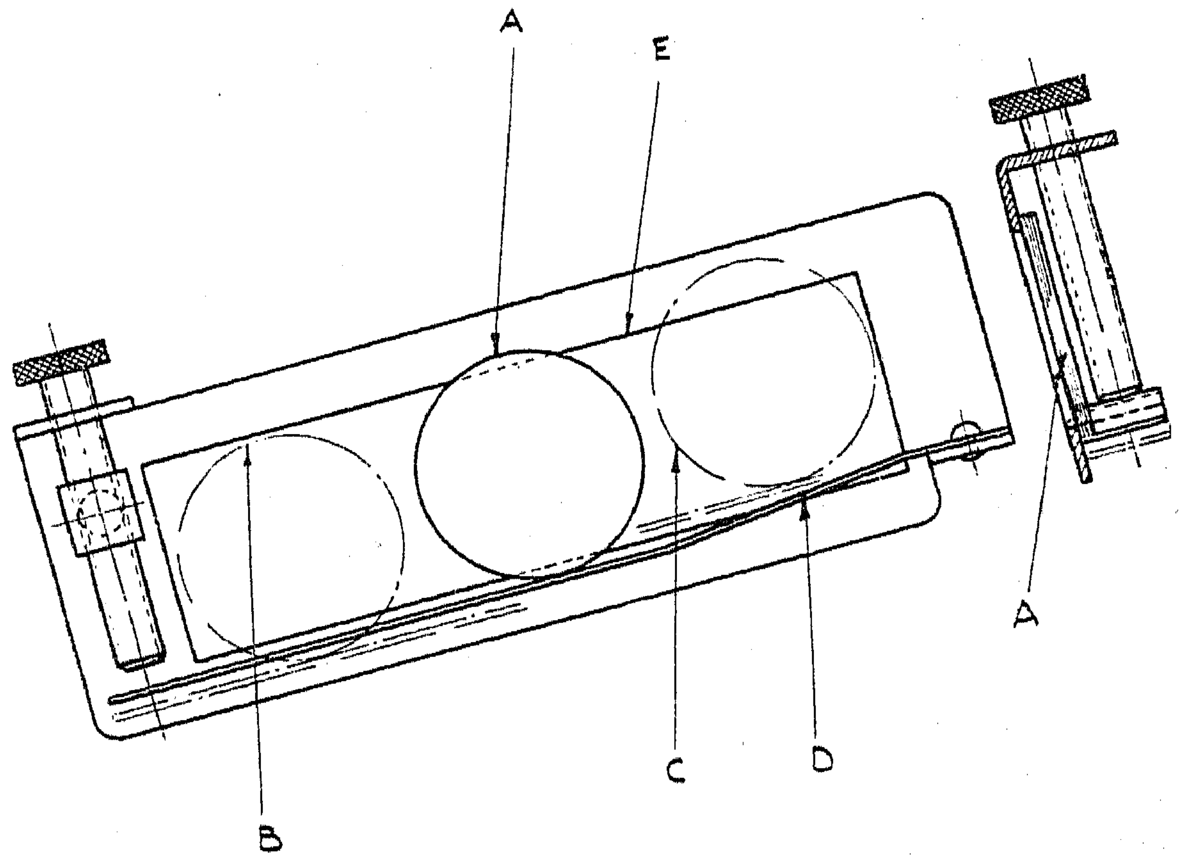

Fig. 4

Holes.

Fig. 5(*c*) shows a device for rejecting coins or discs with holes. The coin in passing down chute A meets gap B. If there is no hole the coin continues, but if a hole is present the coin is caught on lever C, pivoted at D. It then falls to stop E and overbalances lever C, which discharges it.

(*d*) *Rigidity and Elasticity.*

Rigidity tests may be carried out by using the coin as a transmission piece between manually-operated members. The force necessary to operate the mechanism can be used as the gauge of rigidity.

Elasticity may be tested by utilizing the rebound of coins from a hard surface. Correct coins rebound into an " accepted " chute.

(*e*) *Material.*

A method whereby iron or nickel discs may be deflected is shown in Fig. 6 and consists of a pivoted arm A carrying a magnet B, part D being a fixed coin-guide. When an iron disc is used the lever swings over, allowing the coin to fall through aperture C, after which the lever returns to its original position. Other methods employ electro-chemical action and measurement of resistance.

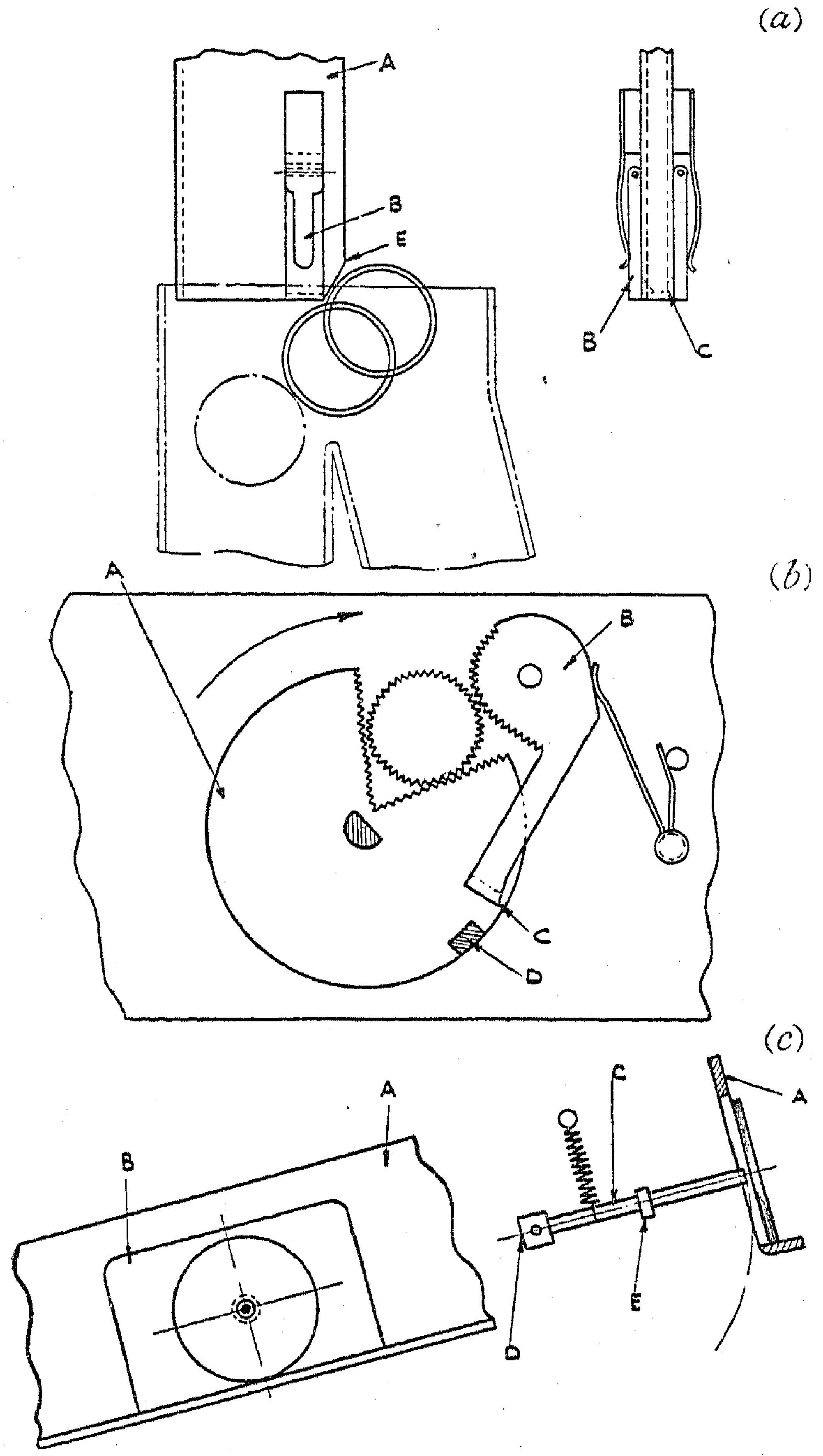

Fig. 5

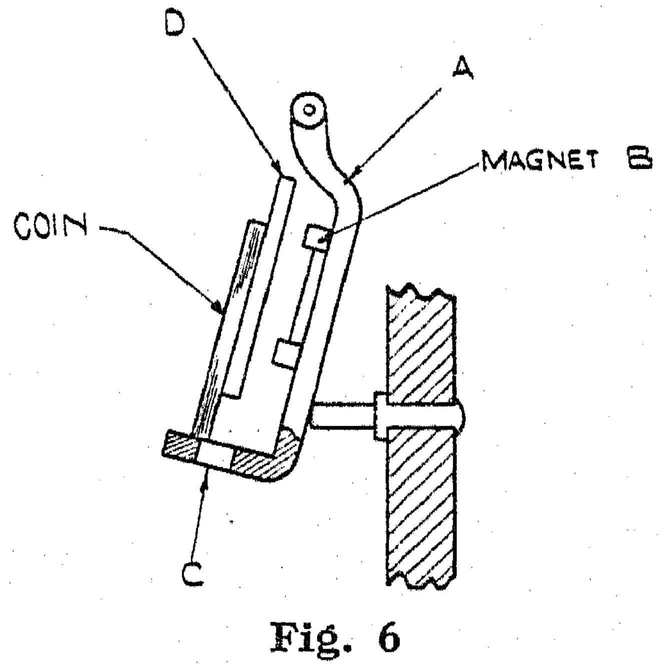

Fig. 6

(2.13). Actuation following coin acceptance.

The work of actuating the mechanism following the insertion of a coin may be supplied as follows:—

(*a*) Energy of dropping coin.
(*b*) Manual.
(*c*) Energy from other sources (mechanical or electrical).

If the coin is of sufficient mass and drops through a sufficient distance it releases energy which may be utilized in operating the mechanism. The work may be supplied by hand, e.g. turning the handle, the coin being used either as a transmission piece or as a means of freeing a catch. Finally, the energy may be supplied from another source such as a wound spring or an electric circuit the switch contacts of which the coin has closed.

(2.14). Price change.

It is not easy to generalize upon the various ways in which this can be performed, but it is probably best visualized in the case where there is mechanical motion and a change in gear ratio produces a change in price.

(2.15). Differential.

The word differential is used here in its widest sense, i.e. to denote a device which utilizes the difference between two motions to control the commodity. They may be classed under two broad headings depending upon the type of delivery:—

(*a*) Where total delivery of commodity takes place immediately following insertion of the coin.

(*b*) Where delivery need not take place immediately or continuously.

(2.16). Storage.

This may or may not take place, and generally does so only where there is discontinuous delivery.

(2.17). Commodity control.

Where storage takes place, the commodity-controlling device generally takes the form of a valve or switch, but in the case of immediate delivery it is a mechanical lock.

(2.2). Coins and Tokens

Since a coin mechanism must be freed by means of a coin it is important to know every property and characteristic of the particular coin as well as its relation to other coins. An indication of the extent of these properties and characteristics has been given under sub-section (2.12), and before going on to consider these points in detail it may be appropriate to consider briefly the development of coins.

It was mentioned in the introduction that coins were probably known before 700 B.C., and in Milne's " Greek Coinage " appears the following: " At any rate there can be little doubt that before 700 the Ionians possessed a plentiful and systematized coinage of electrum and used it for purposes of trade overseas."* However, there appears to be some doubt about this, and according to Angell the first recorded coins were minted about 600 B.C. in Lydia.†

Two important points are similarity (coins that will operate a mechanism in addition to those for which they are intended) and wear. Some idea of similarity may be obtained from the lists in Appendix I in which

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* See Reference (1).

† *Ibid.*, (2).

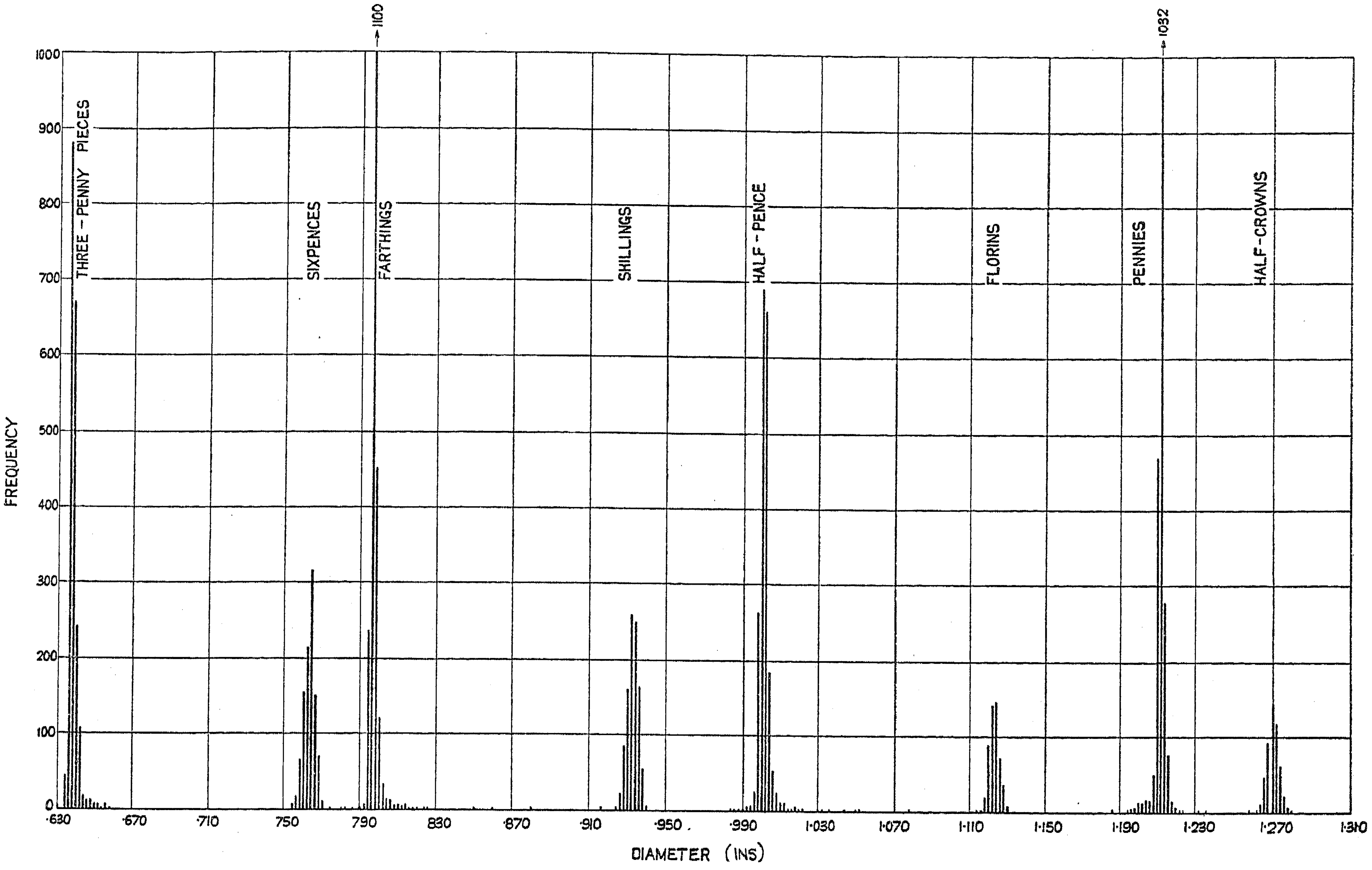
1100
1032
1000
900
800
700
600
500
400
300
200
100
0
FREQUENCY
THREE - PENNY PIECES
SIXPENCES
FARTHINGS
SHILLINGS
HALF - PENCE
FLORINS
PENNIES
HALF-CROWNS
·630
·670
·710
750
790
830
·870
·910
·950
·990
1·030
1·070
1·110
1·150
1·190
1·230
1·270
1·310
DIAMETER (INS)

Fig. 7

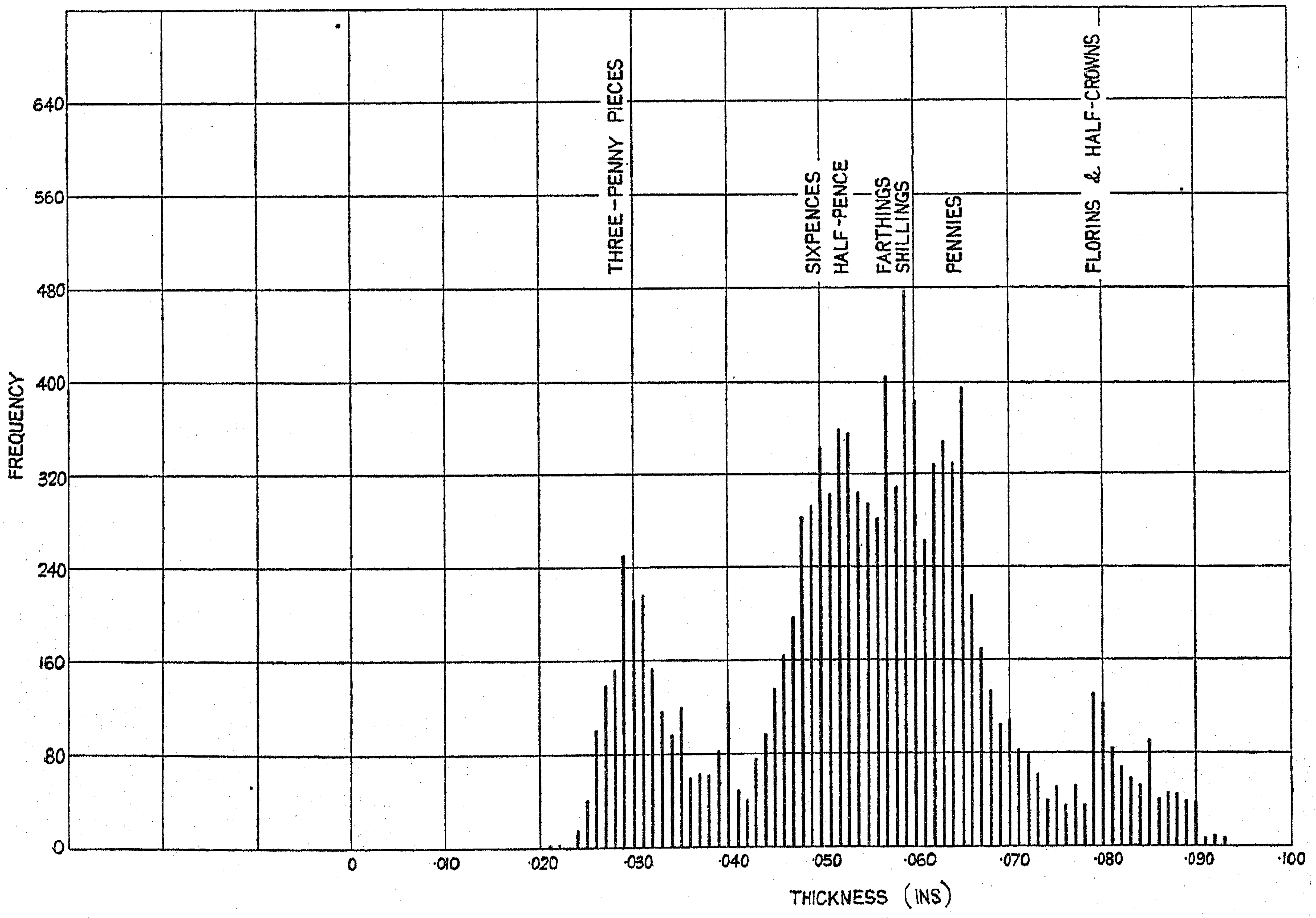
640
560
480
400
320
240
160
80
0
FREQUENCY
THREE-PENNY PIECES
SIXPENCES
HALF-PENCE
FARTHINGS
SHILLINGS
PENNIES
FLORINS & HALF-CROWNS
0
·010
·020
·030
·040
·050
·060
·070
·080
·090
·100
THICKNESS (INS)

Fig. 8

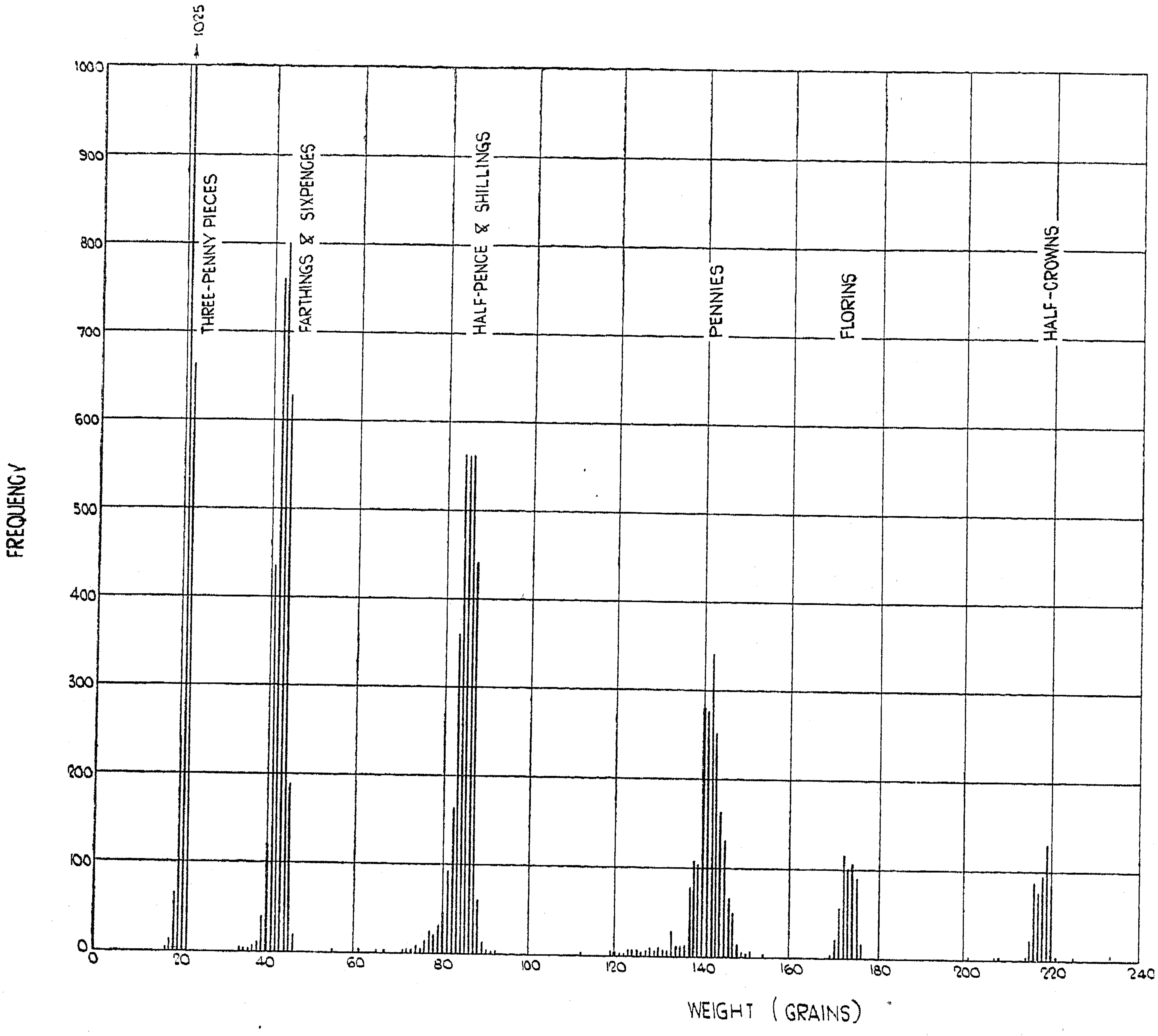
1025
FREQUENCY
1000
900
800
700
600
500
400
300
200
100
0
THREE-PENNY PIECES
FARTHINGS & SIXPENCES
HALF-PENCE & SHILLINGS
PENNIES
FLORINS
HALF-CROWNS
0
20
40
60
80
100
120
140
160
180
200
220
240
WEIGHT (GRAINS)

Fig. 9

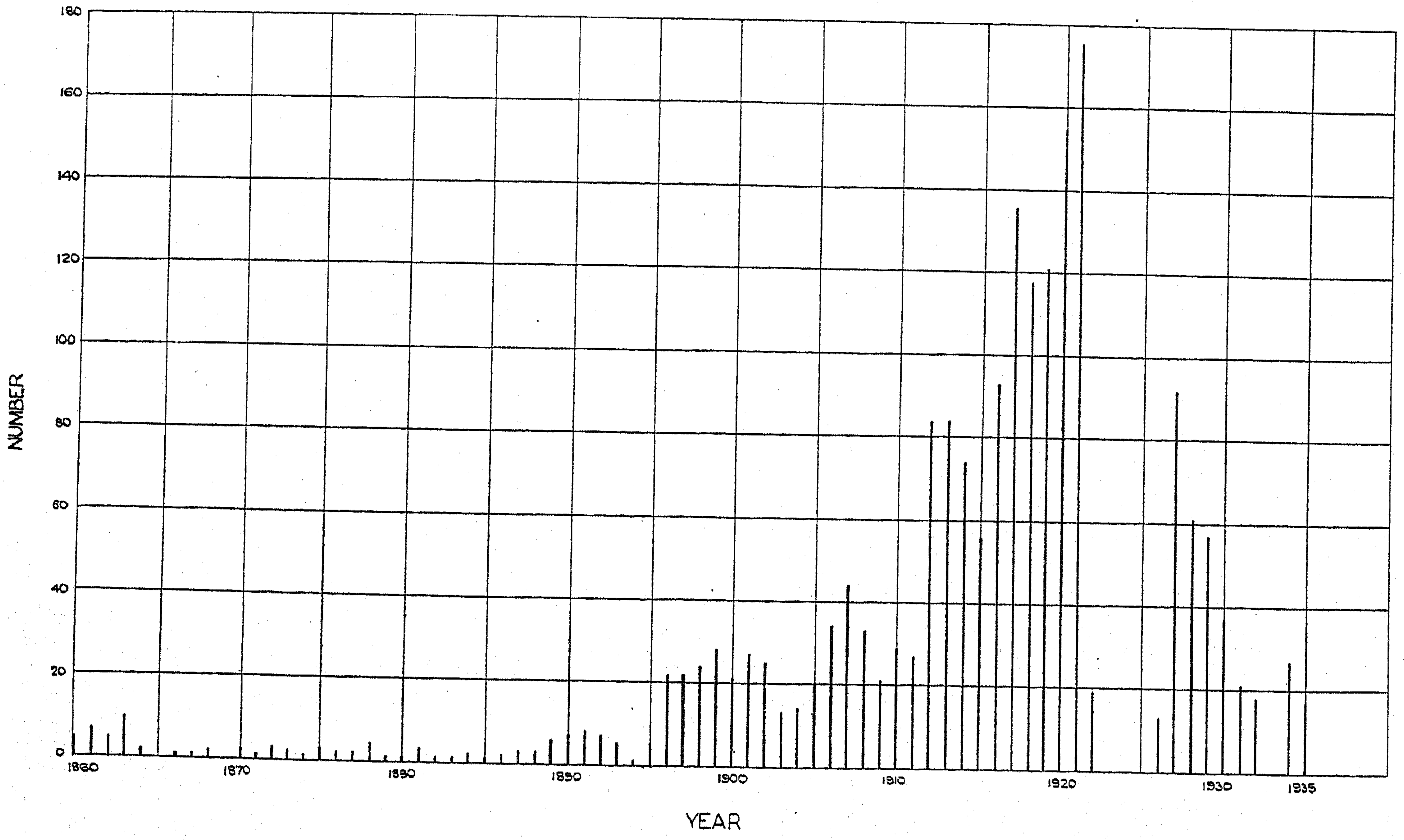
NUMBER
180
160
140
120
100
80
60
40
20
0
1860
1870
1880
1890
1900
1910
1920
1930
1935
YEAR

Fig. 10

an arbitrary selection of coins is arranged, first in order of diameter and then in order of thickness. It will be observed that there are many instances of coins of the same thickness, and some of the same diameter, and this number is increased when a coin is considered to have tolerances. Tolerances have to be considered for three reasons, (*a*) the difficulty of manufacturing a mechanism to accommodate coins of perfect dimension, (*b*) variation in manufacture of the coin, and (*c*) wear.

With the object of obtaining some information regarding coins in circulation an examination of 11 000 coins was undertaken. The distribution was as follows:—

Farthings	2 000
Half-pence	2 000
Pennies	2 000
Threepenny-pieces	2 000
Sixpences	1 000
Shillings	1 000
Florins	500
Half-crowns	500

Care was taken when withdrawing these to ensure that they had not passed through some automatic selector such as might have been the case had they been obtained from an electricity or gas authority. Actually they were obtained from a passenger transport undertaking where coin mechanisms were not used.

Figs. 7, 8, and 9, show the relation between frequency and diameter, thickness, and weight, respectively, and it is at once obvious that there is least overlapping of limits in the case of diameter.

Fig. 10 shows the number of coins of each year found in the 2 000 pennies examined. The earliest coin was 1860 and no coins were found for the following years: 1865, 1869, 1923, 1924, 1925, and 1933.

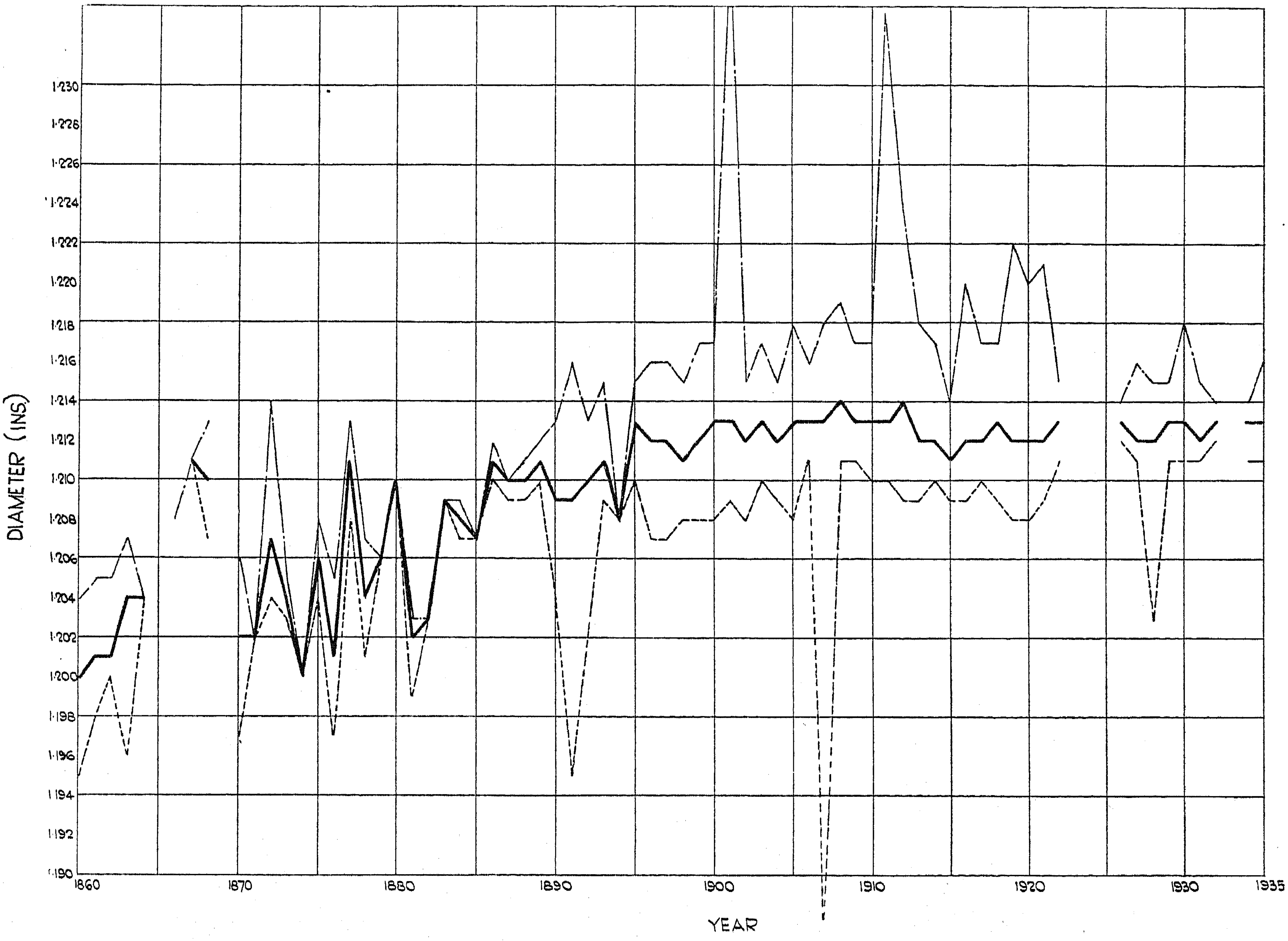

Fig. 11.—Maximum, average, and minimum diameters of 2 000 pennies in various years.

The value of pennies issued by the mint in the years 1923 to 1925 was £180, £380, and £510, respectively, and in 1933, £500: these amounts were very small compared with other years, the year with the smallest amount (during the period 1920 to 1934) being 1932 with £23 230.* Figs. 11, 12, and 13, show the relations between year and maximum, average, and minimum values of diameter, thickness, and weight, respectively.

(2.3). Historical

In the Introduction the authors mentioned the earliest description of a coin device which they have been able to trace. The case is that of a sacrificial vessel from which holy water flows only when money is introduced.

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* See Reference (3).

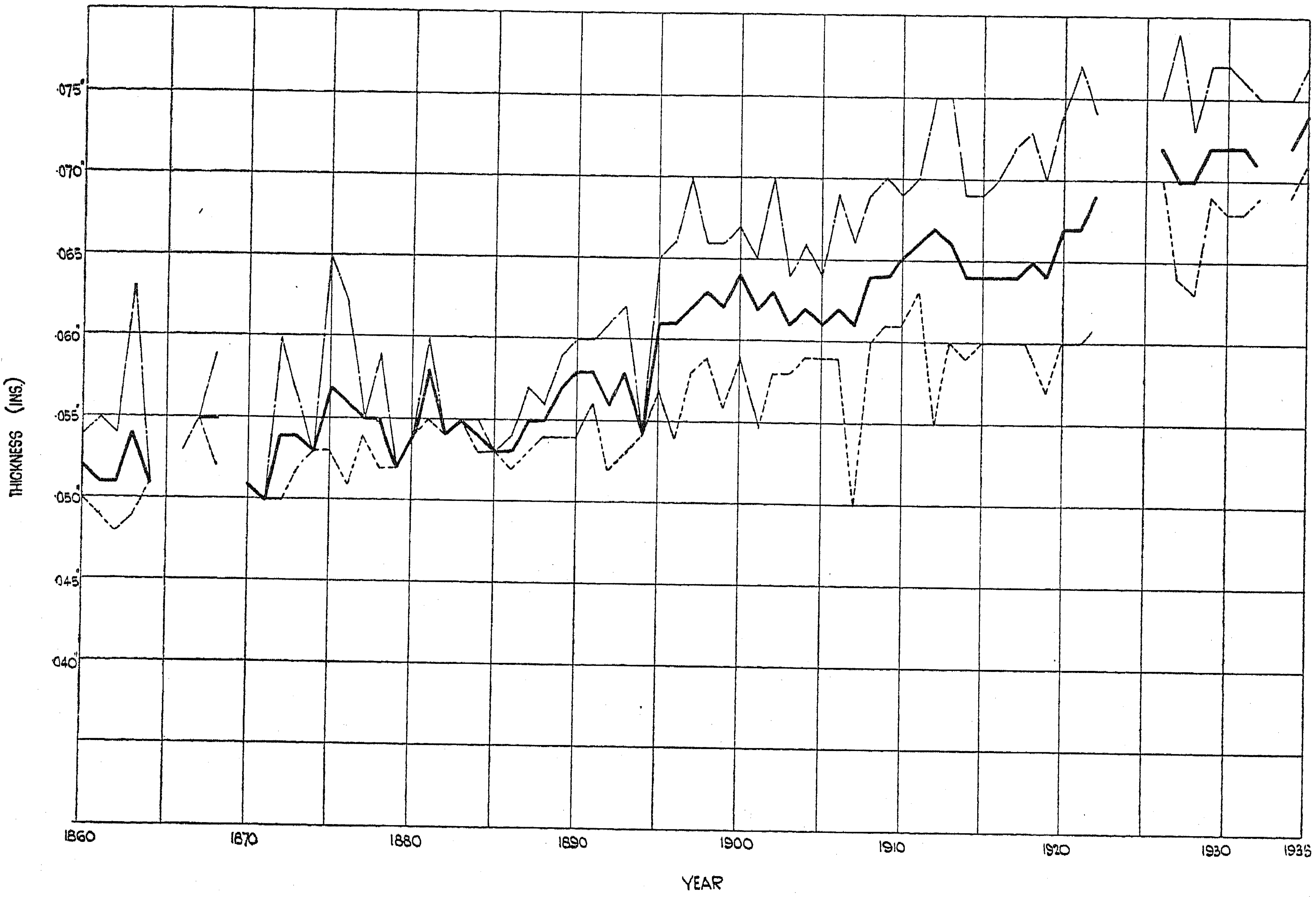

Fig. 12.—Maximum, average, and minimum thicknesses of 2 000 pennies in various years.

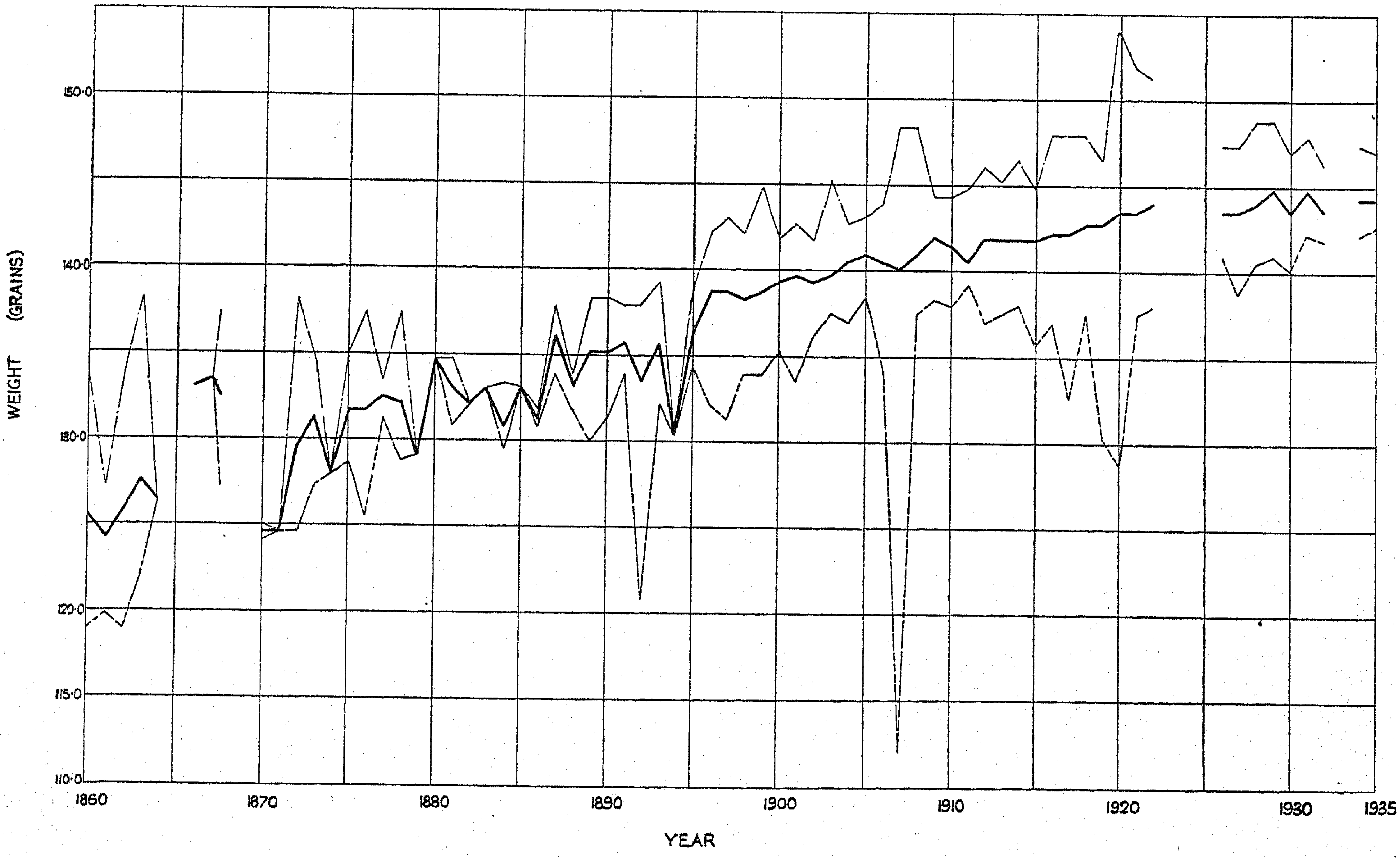

Fig. 13.—Maximum, average, and minimum weights of 2 000 pennies in various years.

It is one of the many inventions of Hero of Alexandria, and puts the age of coin devices at about 2 000 years. It is shown in Fig. 14, and the device is operated by a 5-drachm piece. Greenwood* translates Hero's "Pneumatics" as follows:—

"If into certain sacrificial vessels a coin of 5 drachms be thrown, water shall flow out and surround them. Let ABCD be a sacrificial vessel or treasure chest, having an opening in its mouth, A; and in the chest let there be a vessel FGHK, containing water, and a small box L from which a pipe, LM, conducts out of the chest. Near the vessel place a vertical rod, NX, about which turns a lever, OP, widening at O into the plate R parallel to the bottom of the vessel, while at the extremity P is suspended a lid, S, which fits into the box L, so that no water can flow through the tube LM. This lid, however, must be heavier than the plate R, but lighter than the plate and coin combined. When a coin is thrown through mouth A, it will fall upon plate R, and preponderating it will turn the beam OP, and raise the lid of the box so that the water will flow: but if the coin falls off, the lid will descend and close the box so that the discharge ceases."

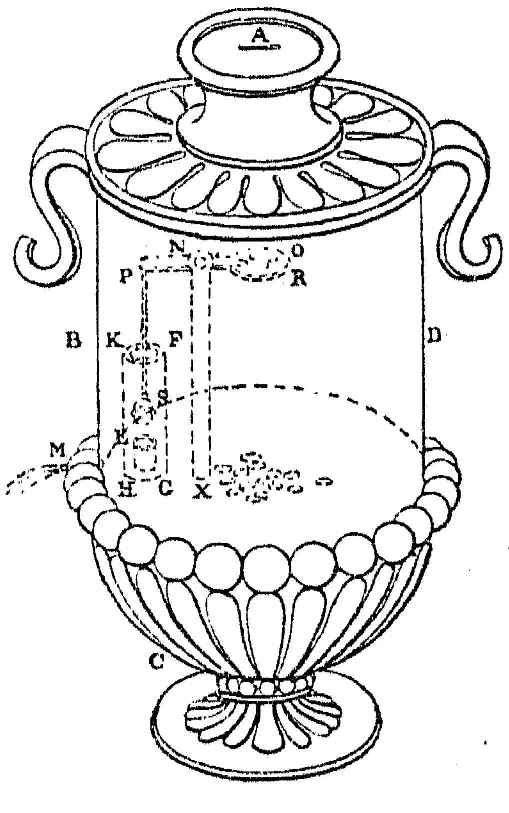

Fig. 14

Another case is that of British provisional Patent Specification No. 706/1857, in which is described a "Self-acting machine for the delivery of postage and receipt stamps." The description is very brief and no drawings are given, but the idea is that underlying the modern stamp machine.

(2.4). Some Particular Cases

It will be of interest to consider some coin mechanisms as they are at present adapted to various applications.

(2.41). Vending machine.

In this the commodity is completely delivered by the operation of coin mechanism.

A typical and well-tried example is that shown in Fig. 15. The articles to be delivered are stacked vertically, the bottom one resting in a sliding tray. Efforts to slide the tray without the insertion of a coin are prevented by a pivoted catch engaging with a stop on the frame. The insertion of a coin merely raises this catch when the tray is moved. The multi-toothed pawl ensures the full forward movement of the tray before it can be returned.

(2.42). Stamp machine (Figs. 16 and 17).

Here coin test takes place on diameter and weight, and actuation is manual.

The coin is caused to enter the aperture (oversize coins cannot be inserted) and encounters lever 8 rigidly attached to pivoted weight 8A. The weight is thus raised and energy is stored for the subsequent operation of the mechanism. The coin then rolls down chute 6 and coins of small diameter are rejected and returned. The accepted coin now depresses lever 13 and frees wheel 11, allowing a given amount of freedom. Wheel 11 now rotates under the influence of a rack attached to the lower end of lever 9 which is operated by the falling weight 8A. Rigid with wheel 11 is feed drum 10 which feeds forward one stamp.

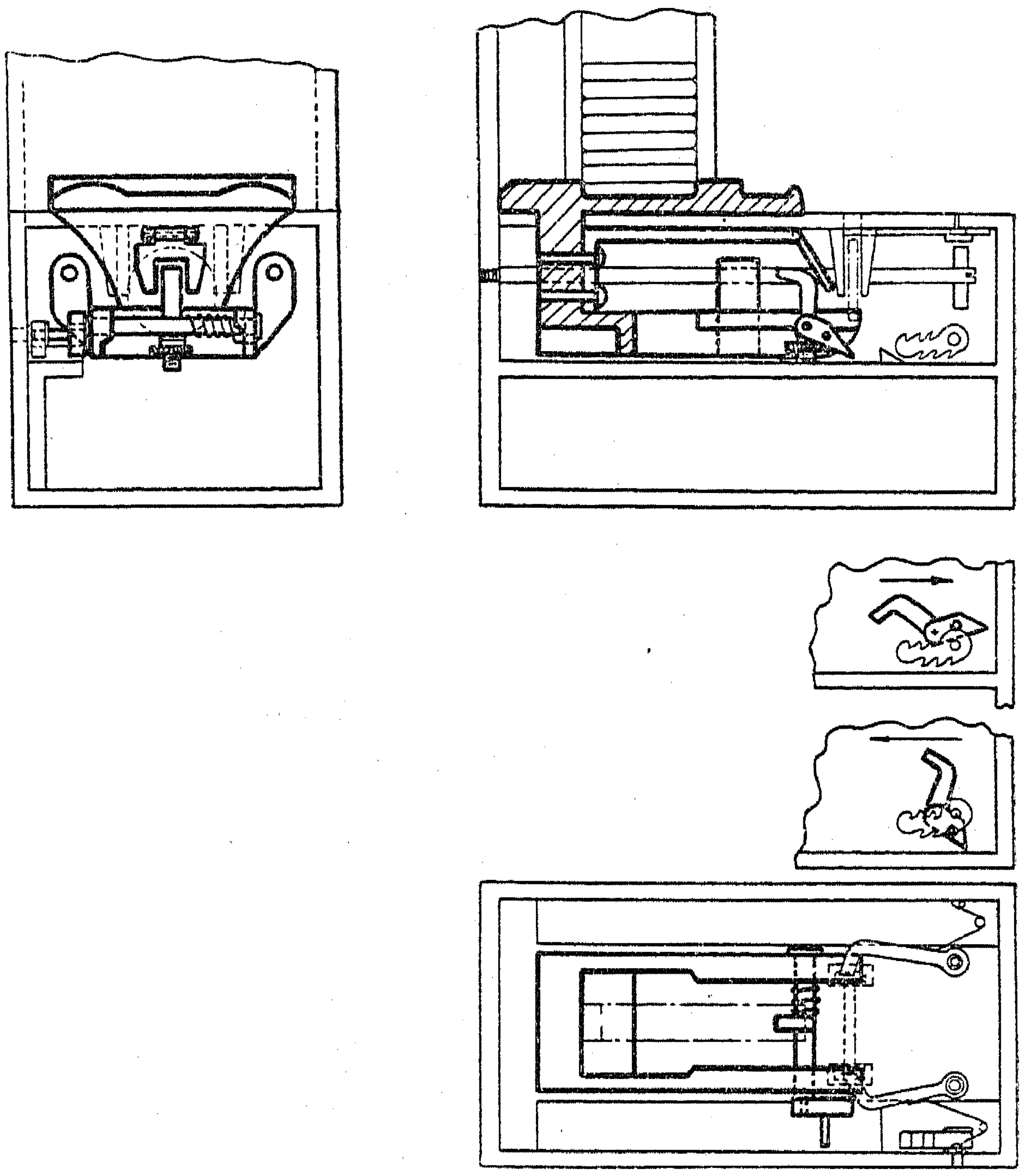

Fig. 15

(2.43). Telephone mechanism (Fig. 18).

The tests on the coin take place first of all on diameter, and secondly on weight, and three separate sets of coin-testing mechanisms are provided, one for each coin denomination. The first operation is that the receiver is removed, cutting out the ringing circuit and connecting the speaking circuit. The first penny inserted closes contacts 10 and 11 and opens contacts 11 and 12, short-circuiting the speech transmitter and removing the short-circuit from a gong transmitter in the coin mechanism. The penny is now at rest on the balance arm, which is not tilted until the second penny is inserted. Contacts 4 and 5 are opened and 3 and 4 closed, removing the short-circuit from the impulse springs of the dial. The caller is now able to dial the subscriber. When the called subscriber answers, the caller depresses button A, thus depositing the coin in the cash box, opening contacts 10 and 11, closing contacts 11 and 12, and 4 and 5, and so transferring the short-circuit from the speech transmitter to the coin-box transmitter. The closing of contacts 4 and 5 restores the short-circuit across the dial impulse springs. The circuit is now normal. If the caller is unsuccessful he presses button B and the money is returned to him.

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* See Reference (4).

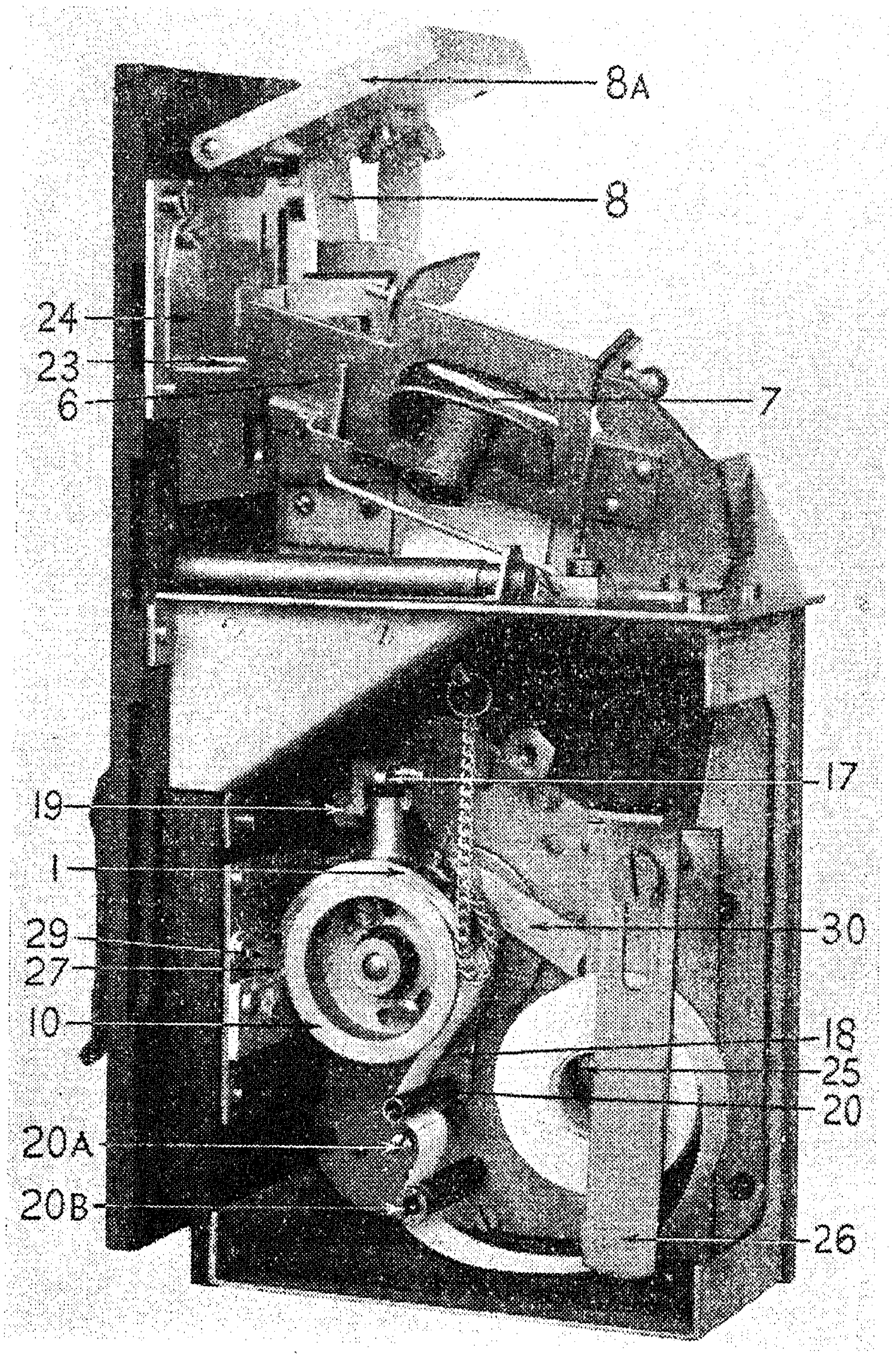

Fig. 16

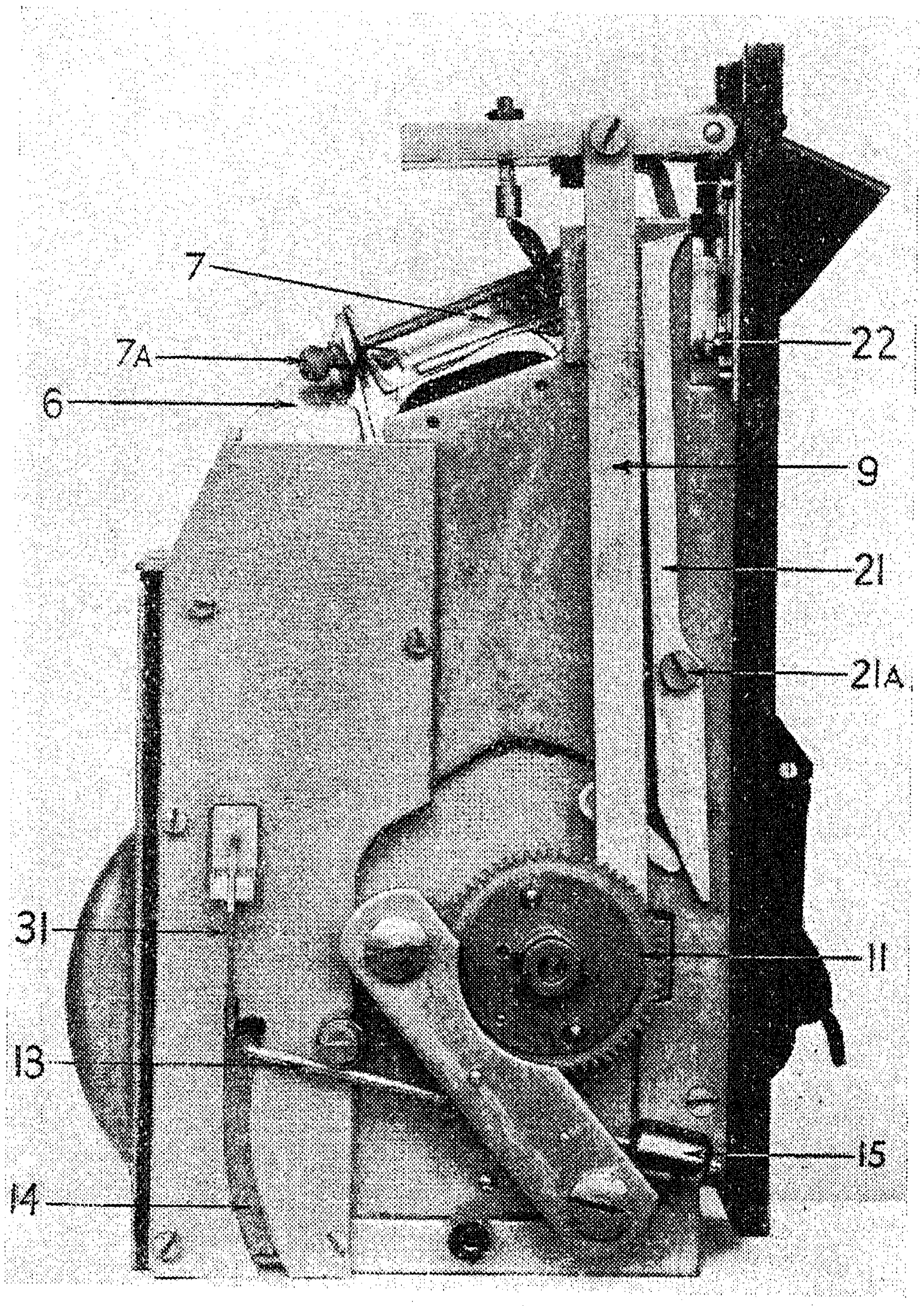

Fig. 17

(3) ELECTRICITY METERS

(3.1). Historical

Before considering the prepayment meter in any detail it is useful to review some of those that have been used. Whilst in general prepayment mechanisms have been adapted to meters giving mechanical motion, there have been one or two cases where this motion has not been available and where special adaptation has been necessary. Also prepayment mechanisms have been applied to devices which are not strictly meters but which have allowed energy to be taken in some proportion to the coins inserted. Notable among these are the Watson Electric Slotter and the Mordey-Fricker.

(3.11). Watson Electric Slotter.

The coin receiver consists of a rotating cylinder (see A, Fig. 19). The coin on leaving the cylinder frees lever B. If it is too large it will not enter the receiver, and if too small or too light it will not depress lever B. Coin spindle C is now free and on rotation by handle actuates drum D, which, in effect, is the differential of this mechanism. The distance through which the drum moves can be controlled by adjusting the surface length of cam C_1. This forms an effective price-change. Connected to the same spindle as drum D is a dial reading in lamp-hours. This is the storage indicator. The switch is also closed on rotation of cam spindle C by means of a further cam E.

When current is being consumed coil F attracts the armature on lever G. At the extreme end of G is an extension G_1 which controls the maximum permissible movement of swing member H. This member is oscillated during current consumption by cam J which is driven at constant speed by a spring-energized clock. Member H during oscillation actuates pawl K, which, in turn, varies the rate at which a second spring-controlled train runs down. When the stored number of lamp-hours have been consumed the second train has driven back drum D to zero, at the same time moving tripping lever L and allowing the switch to trip.

(3.12). Mordey-Fricker.

This meter was of the electrolytic type and consisted essentially of two copper electrodes in a bath of copper-nitrate solution. On the passage of a current, copper was taken from the anode and deposited on the cathode, the increase in weight of which gave a measure of ampere-hours. In its application to a prepayment meter, facilities were provided for a given amount of anode copper to be introduced into the solution on the insertion of a coin. When the whole of this copper had been deposited on the cathode the circuit was open and further supply obtainable only on the insertion of another coin. The actual construction will be clear on reference to Fig. 20, where A is the glass container for the electrolyte. The coin is introduced into the receiver B and forms a transmission piece between parts

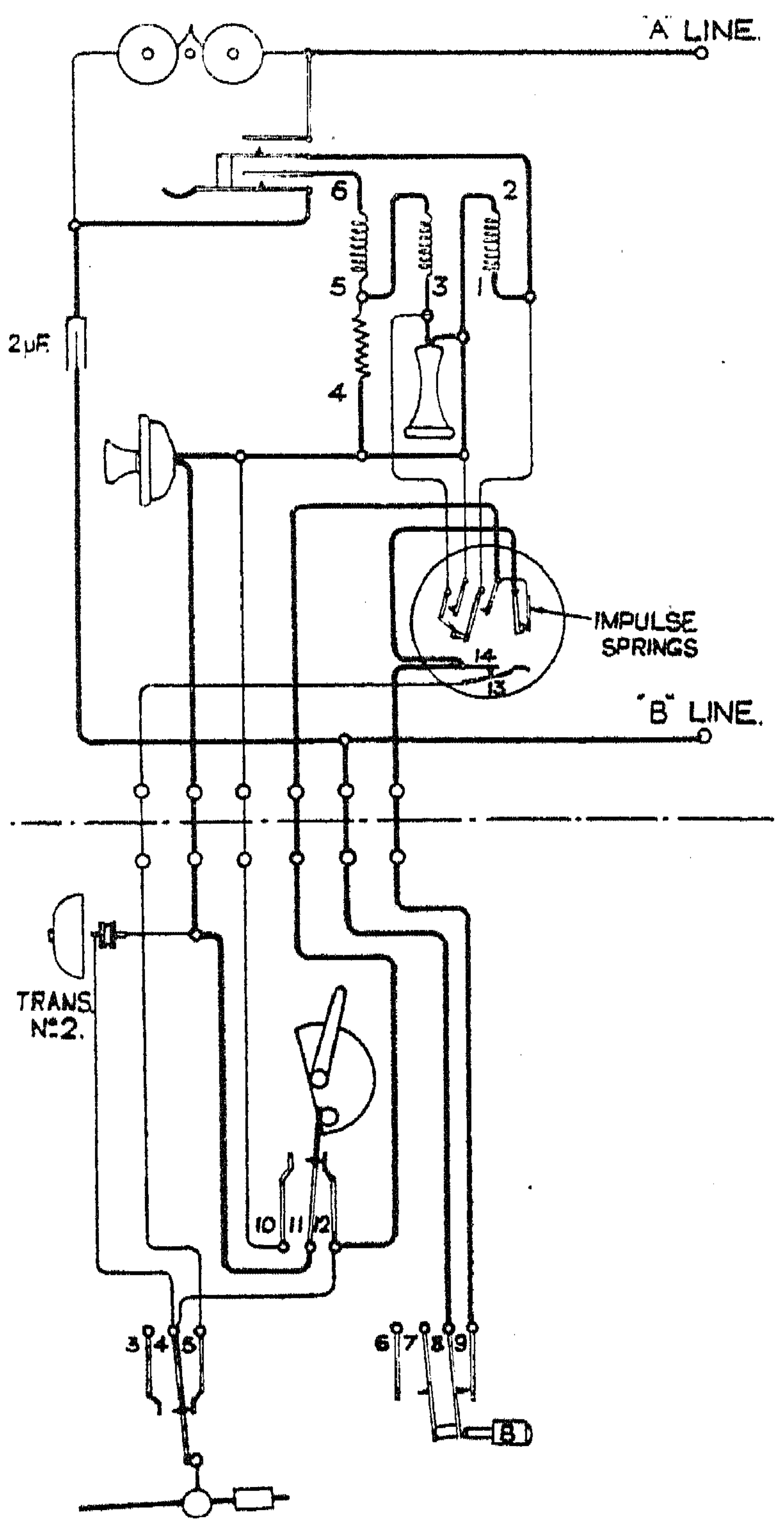

Fig. 18

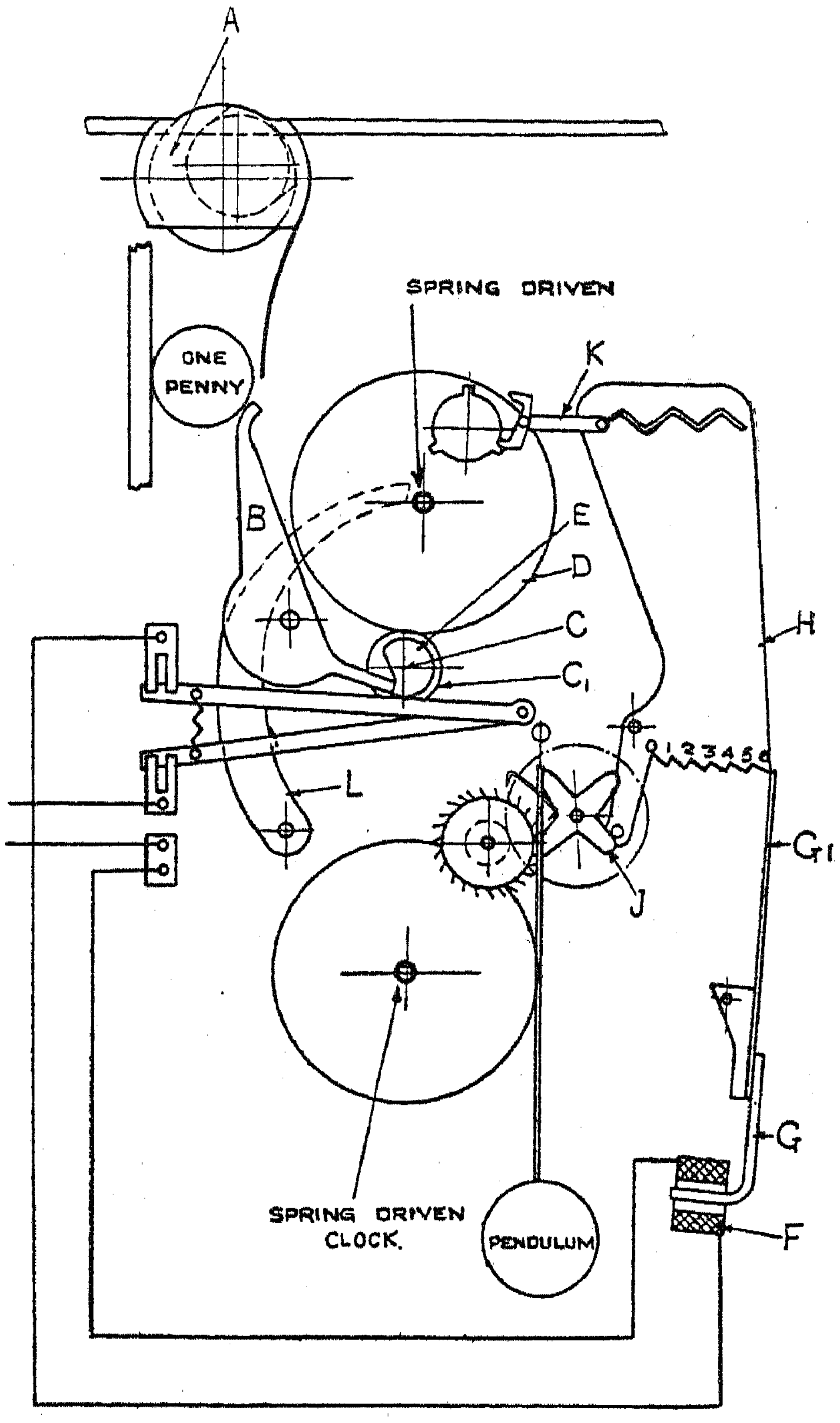

Fig. 19

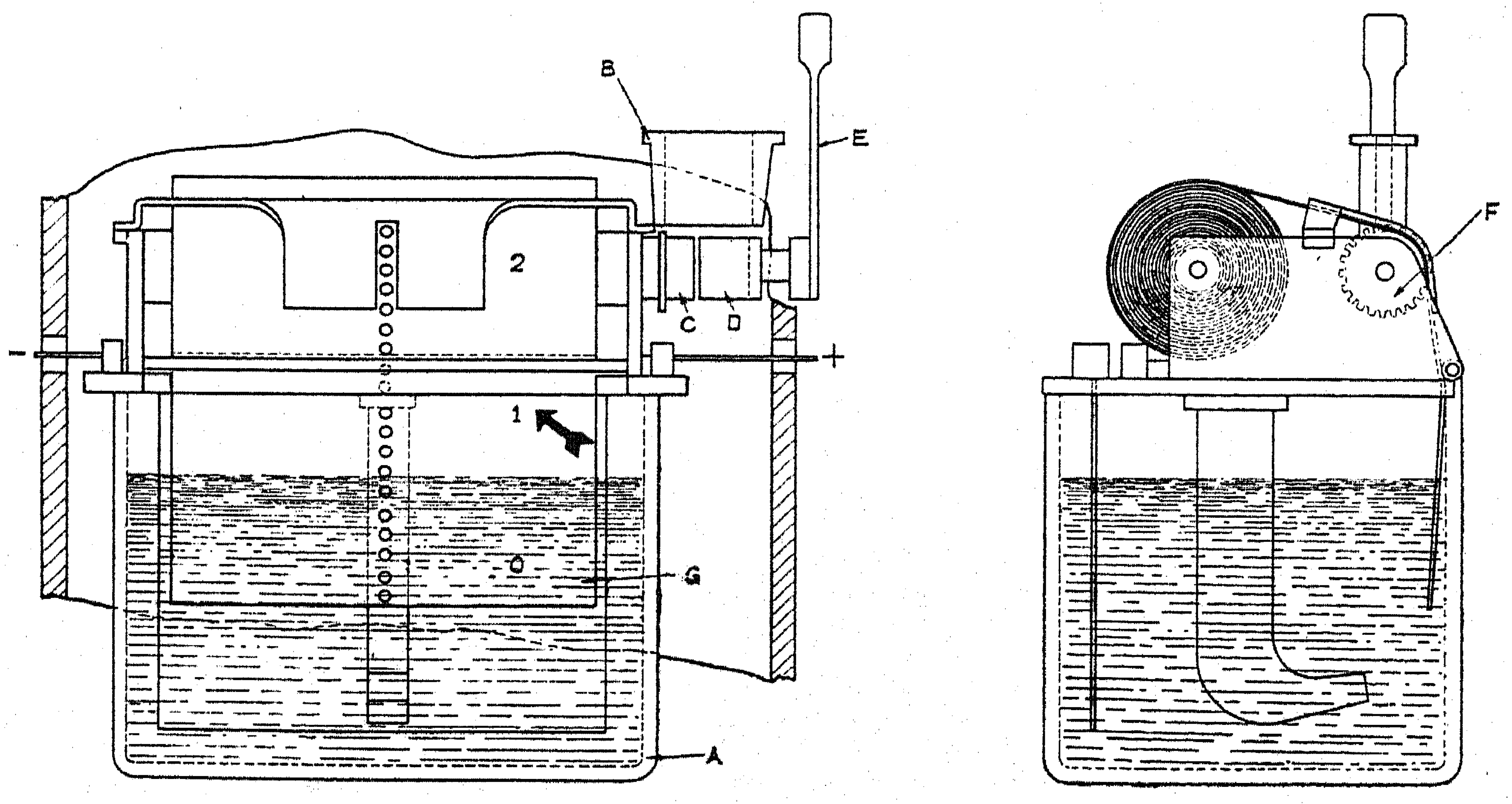

Fig. 20

C and D, operation thus being dependent upon rigidity of the coin. Actuation of coin lever E allows rotation of member C to which is attached sprocket wheel F. This engages with a series of holes in copper anode G and allows a fixed amount to enter the electrolyte. The anode is marked at intervals with numbers which indicate the total number of coins inserted. On the passage of a current, the anode gradually disappears and the circuit is eventually broken as described above.

(3.2). Influence of Tariffs on Design

Tariffs may affect the design of a prepayment meter as a result of type, magnitude, or change in magnitude or type.

There is in existence a very large variety of tariffs, and in recent years a great deal has been written on the subject. It is not intended to consider them in great detail but merely to outline the main variations and to consider their effect on prepayment meter design.

Whatever particular opinion may be held, it will probably be agreed that the ideal tariff is one which completely meets the liabilities of the supply undertaking under all conditions and at the same time promotes the use of electricity.

Most tariffs involve (*a*) time of use; (*b*) actual or assessed rate of use; (*c*) purpose for which used; and (*d*) quantity used.

The principal tariffs are briefly described below, together with a consideration of their effects on the meter.

(3.21). Flat rate.

This tariff consists of a uniform price per unit, irrespective of any other factor. Under it, revenue is collected by means of the basic prepayment meter consisting of a coin mechanism in conjunction with a meter element.

Occasional changes in the magnitude of the tariff necessitate the provision of facilities for changing the effective gear ratio between the meter and the coin spindle (Figs. 21*a* and 21*b*).

(3.22). Flat rate with minimum charge.

This consists of a flat rate conditional upon a certain consumption. As far as the authors are aware there has been no demand for a prepayment meter to collect revenue under this tariff.

(3.23). Lighting and power.

This tariff comprises two separate flat rates of different magnitude, of which "power" is usually the smaller. Two separate circuits are used for the different types of consuming apparatus.

The following arrangements may be used:—

(*a*) Meter for each circuit.

(*b*) Meter embodying one mechanism and two measuring elements.

(*c*) One meter embodying double-element current unit.

Two basic prepayment meters (Fig. 21*b*) meet the first case. The second (Fig. 21*c*) necessitates special arrangements for the summation of the two motions and probably an increased-capacity switch. The third (Fig. 21*d*) results in an increased-capacity switch, and, owing to the fact that true units are not registered, the loss of ability to check the number of units consumed against money inserted.

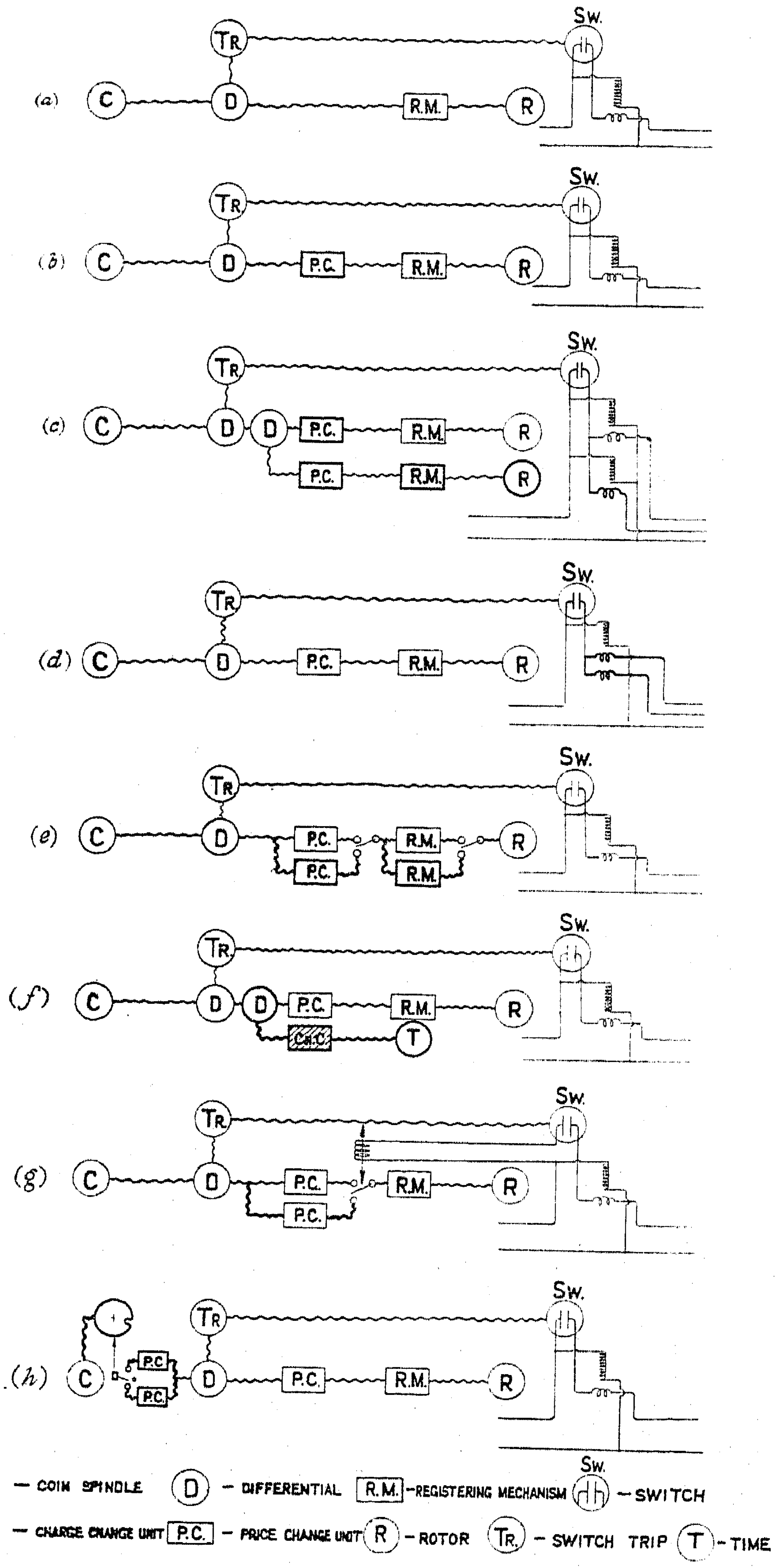

Fig. 21

(3.24). Time tariffs.

These are:—

(*a*) Multiple flat rate, the change-over from one rate to another being with respect to time. This may be time of day or night, day of week, or season of the year.

(*b*) Simple flat rate with cut-off at certain times of the day.

The change from one rate to another is automatic except in the case of the seasonal change, which may be manual. Collection of revenue under (*a*) necessitates the provision in the prepayment meter of more than one price-change device, and may necessitate more than one unit train together with a time-controlled change-over mechanism (Fig. 21*e*). Collection of revenue under (*b*) can be met by means of a basic prepayment meter in conjunction with a time-controlled switch.

(3.25). Fixed charge without unit charge.

In this a fixed charge is assessed upon the maximum requirements of the consumer, and an agreed sum is paid for a given setting of a load limiter without any unit charge.

A mechanism operated by a time device can be used in conjunction with the limiter to collect this charge.

(3.26). Fixed charge plus running charge (two-part tariff).

This consists of a charge independent of consumption, in addition to the unit charge. Its primary object is an endeavour to meet the large fixed liabilities of the undertaking in accordance with the principles outlined by the late Dr. Hopkinson.

The methods mostly in use are:—

(*a*) The fixed charge is assessed on the kVA or kW demand, the actual charge depending upon the maximum or on an agreed sliding scale.

(*b*) The tariff is assessed upon the maximum requirements of the consumer, and a fixed sum is paid for a given setting of a load limiter in addition to the meter unit charge.

(*c*) The tariff is based upon some convenient factor, such as lamp wattage, rateable value of premises, area of rooms, number of rooms, or some combination of the foregoing.

In general the application of tariffs under (*c*) is less expensive than that under (*a*).

The meter now known as the two-part tariff meter meets the requirements of (*c*). It consists of a simple prepayment meter actuated, in addition to the meter, by some time device (Fig. 21*f*). Regarding (*a*), no call is made for the adoption of the prepayment meter.

(3.27). Unit charge depending upon short-time rate of consumption (load rate).

The feature of these tariffs is a change in price per unit depending upon the short-time rate of consumption. The change may be an increase or decrease in the price with increased demand.

In practice these are carried out by the use of two price-per-unit mechanisms, the change-over being effected by means of a load-sensitive relay (Fig. 21*g*).

(3.28). Sliding scale relating to quantity (step rate).

Under this system a change in price per unit takes place after a certain number of units have been consumed or paid for, the change being to a cheaper rate. Resetting takes place after certain predetermined periods, and is performed either manually or automatically.

The prepayment meter in this instance is modified by the addition of another price-per-unit mechanism, the change-over taking place from a pre-set mechanism arranged in units or coins after the number has been collected (Fig. 21*h*). In addition the automatic reset to the higher price can be effected by an additional time device.

(3.3). Meter Mechanisms

Most modern electricity meters are motor meters, that is, mechanical motion is available to operate a prepayment mechanism. The fact that the mechanism has not to be so widely adaptable has naturally resulted in mechanisms conforming more to a type.

Meter mechanisms have been considered as follows:—

(3.31). Single coin.
(3.32). Optional coin.
(3.33). Meters for special tariffs.
(3.34). Performance.

(3.31). Single coin.

The various points of Section (2.1) will now be considered, so far as they relate.

Coin Test.

Similar methods to those described in Section (2.1) may be employed, but generally only methods (*a*) and (*d*), i.e. dimension, and rigidity and elasticity, are used.

Price-Change.

This may occur anywhere between the coin handle and the meter train, and is shown in two positions in Fig. 2.

The following methods may be employed:—

(*a*) Dismantling of certain parts, and the substitution of new wheels. (This may mean returning meter to test room and sometimes to manufacturer.)

(*b*) Use of removable unit, involving

  (i) Removal of complete cover.
  (ii) Opening of portion of cover.

(*c*) Variable-gear unit controlled from outside of cover.

Price-change is generally carried out by altering the gear ratio between the coin handle and train, or the angular motion per coin of the coin handle. In any case the gear ratio or the angular motion is directly proportional to the price of energy in units per coin. It may be noted that price can be expressed in " units per coin " or " pence per unit " and that one is proportional to the reciprocal of the other. It is a matter probably of personal opinion which is to be used, but it should be borne in mind that equal increments of one do not represent equal increments of the other. If the price is to be changeable in equal steps of " units per coin " then the angular motion or gear ratio of the price-change unit will also be in equal steps.

The essential difference between having the price-change unit on the coins side and on the meter side is that in the former case the sun wheel of the differential moves equal angular amounts per unit, whilst in the latter case it moves equal angular amounts per coin (Fig. 22). A consequence is that in one case the storage indicator attached to the differential indicates units and in the other money, and this imposes certain limitations on special meters to be described later.

It may be useful to consider the various ratios involved.

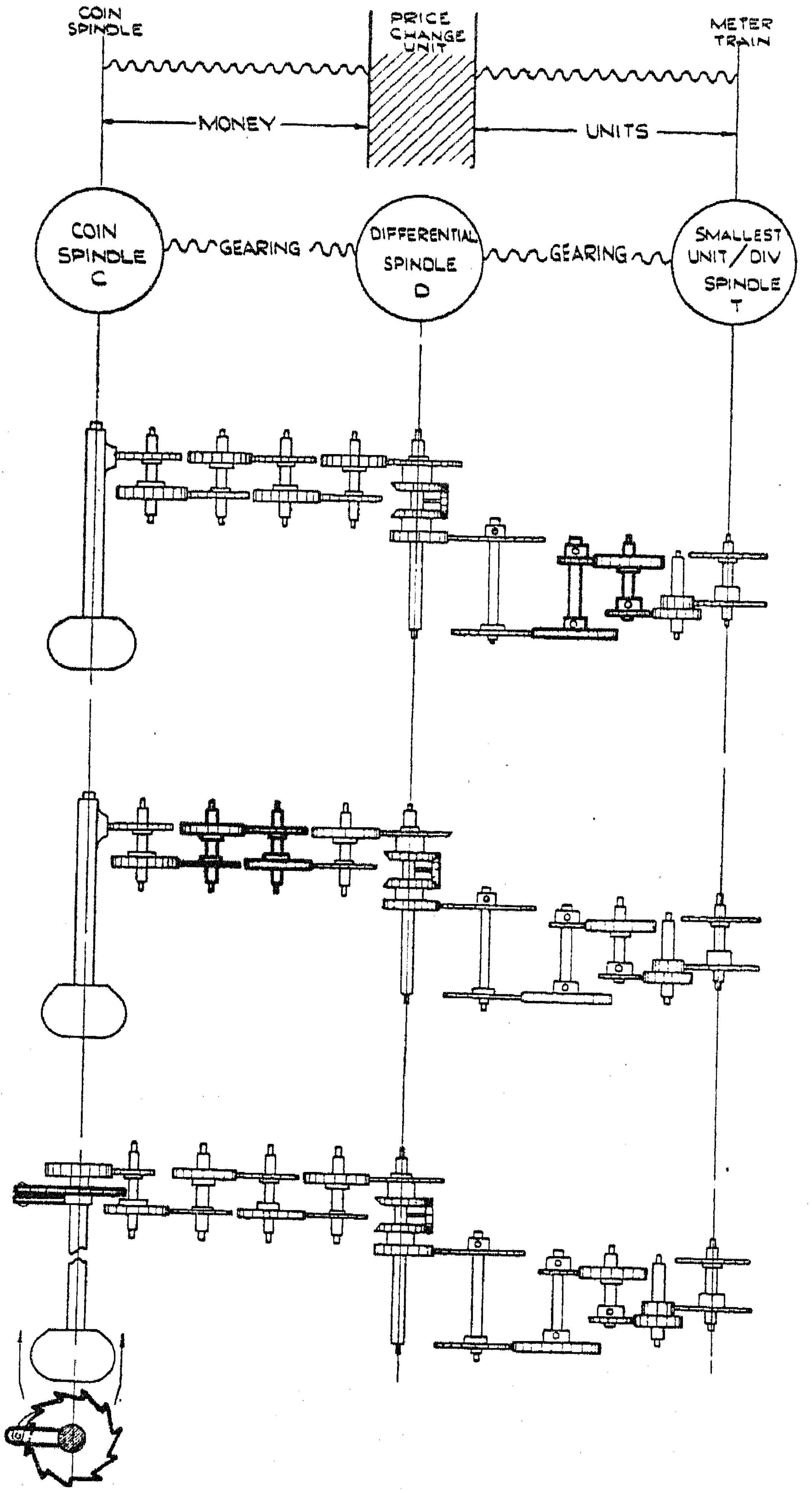

Fig. 22

They are shown below expressed in terms of the meter constants* (see Fig. 23).

Let S = full-load speed of rotor (r.p.m.).
K = full-load kilowatts.
R = rating of smallest dial/division.
P = price per unit (pence).
A = angular movement of differential sun wheel per penny (degrees per penny).
ϕ = movement of differential sun wheel (degrees per unit).
θ = degrees of coin spindle per penny.

(1) *Ratio of differential to rotor.*

$$\text{Ratio} = \frac{\text{Revs. of sun}}{\text{Revs. of rotor}} = \frac{APK}{21\,600S}$$

(2) *Ratio of train (smallest dial) to rotor.*

$$\text{Ratio} = \frac{\text{Revs. of smallest dial}}{\text{Revs. of rotor}} = \frac{K}{600SR}$$

(3) *Ratio of Coin Spindle to Meter Train.*

$$\frac{C}{RM} = \frac{\theta RP}{36}$$

(4) *Price-Change on Meter Side of Differential.*

$$\frac{D}{RM} = \frac{ARP}{36}$$

(5) *Price-Change on Coin Side of Differential.*

$$\frac{C}{D} = \frac{P\theta}{\phi}$$

Differential.

The actuation is often performed merely by direct gearing between the coin-test mechanism and the differential, but sometimes it takes the form of a single-

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* See also Appendix II.

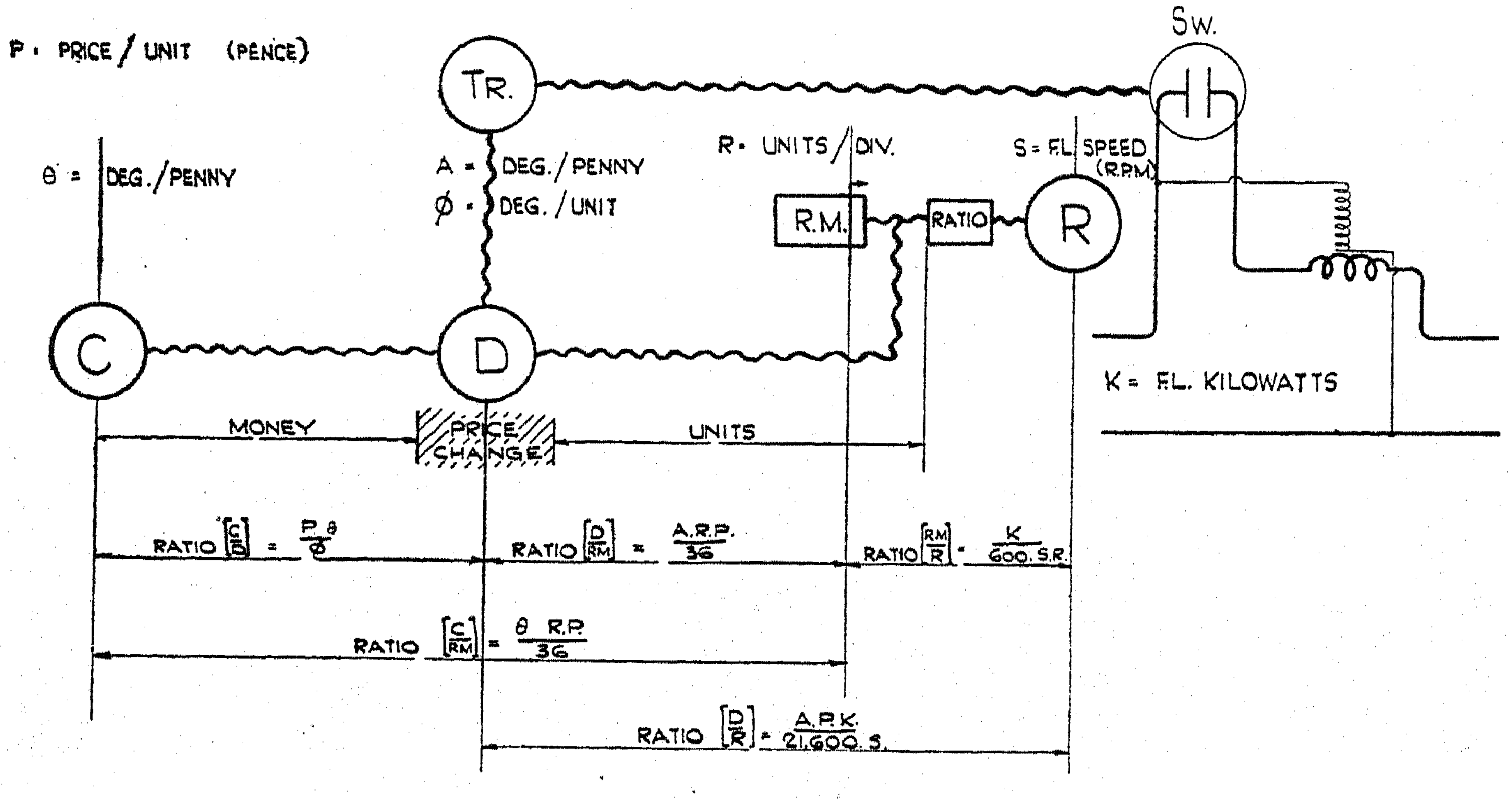

Fig. 23

tooth drive. The types are (*a*) Sun-and-planet system; (*b*) Screw-and-nut system; (*c*) Two wheels and relative positive motion (Fig. 24).

A sun-and-planet system is now the most generally adopted.

Storage.

One point of importance with many users is the number of coins that may be inserted and stand as credit at any one time. If the meter has only a small capacity in this respect one of two things may happen.

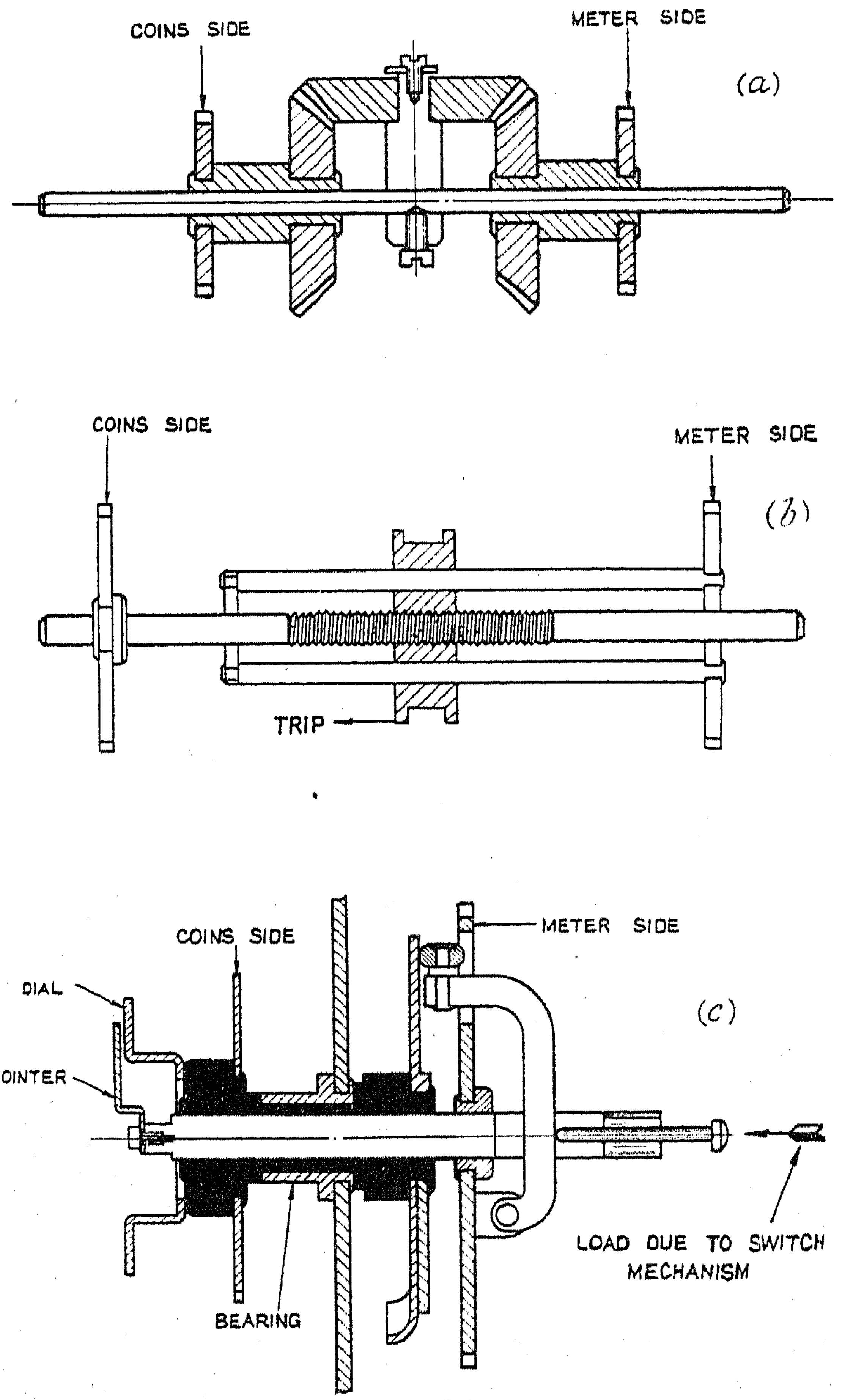

Fig. 24

It may be filled to capacity, with the result that important parts may be broken during the attempt to insert further coins, or certain parts may slip, with consequent loss of money to the consumer. These points result in inconvenience both to the supplier and consumer, and, in the case of damaged parts, direct money loss to the former. Apart from a warning notice or device two methods are available to overcome it; the capacity may be made very large, or the coin receiver may be fitted with a coin-slot-closing device.

This feature of large storage capacity is likely to become of still greater importance with the optional-coin fixed-charge meter.

In addition to large storage the necessity arises for a clear indication of the number or value of the credit.

Switch Control.

By this is meant the mechanism controlling the closing and opening of the switch contacts. In a prepayment meter these operations are usually carried out by two separate devices, closing being performed by the coin handle and opening by the differential.

The closing of the switch should be performed by means of a free-handle device, because any uncertainty of contact and any opening and closing by the person operating the mechanism would result in heating and possibly reduce the life of the switch, or even destroy it. The closed position of the switch must be stable and unaffected by vibration or shock. The switch must open without imposing excess load on the meter, and therefore should not require large effort to open.

Switch.

A switch for use in a mechanism should have two features developed to a higher degree than is usual. Its size, and the work necessary to operate it, should be small. It should be small in size since it has to go inside the meter case and there is a definite demand for small meters. It should not require much work to operate it, because in general it is closed by means of the handle and opened under the influence of the meter.

It is to be noted that the design of a switch may be different according to whether it is to operate on alternating or direct current. The d.c. switch will in general have a longer break and occupy more space. The main types are, (*a*) butting contacts, (*b*) drum or commutator, (*c*) mercury, (*d*) wiping contacts.

(*a*) *Butting contacts.*

With butting contacts, the " cling " between surfaces when the switch is tripped is negligibly small, and in consequence the margin of pull-off force is always ample.

It is sometimes claimed that sliding surfaces keep contacts clean, and in general this advantage is absent in the case of butting surfaces.

(*b*) *Drum or commutator.*

Here the chief feature is that of sliding contacts, and no difficulty should arise due to bad contact. The cling between surfaces is considerable, since in general it is equal to the contact pressure.

(*c*) *Mercury.*

Much of the early prejudice against the electrical performance of these switches has disappeared and many forms are now available. The break may take place in air or in a suitable gas and at various pressures. There is no cling, and little work is required to operate them. Two disadvantages are that, in general, flexible connection leads are employed and the space occupied is great, especially in the larger ratings. The features of these switches were discussed in an article by A. Pestel.*

(*d*) *Wiping contacts.*

These switches have much in common with those under (*b*) so far as electrical features are concerned.

Money collection arrangement.

One important point which reflects directly on the meter design is control of the money collection. Where the technical department does not make the collection it is important for the meter to be completely inaccessible when the coin box is removed.

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* See Reference (5).

With the object of obtaining some reliable information on this point, the practice regarding responsibility for money collection of 301 undertakings involving 3 628 751 meters (2 529 849 quarterly and 1 098 902 prepayment) was examined. Of these undertakings 58 per cent gave the responsibility to the treasury department, 40 per cent to the meter department, and in the remainder both departments had access. This shows no marked tendency in either direction but what is probably of greater interest is the number of meters attended by the various departments. It is evident from Table 3 (see page 541) that the majority of prepayment meters are attended by the treasury department.

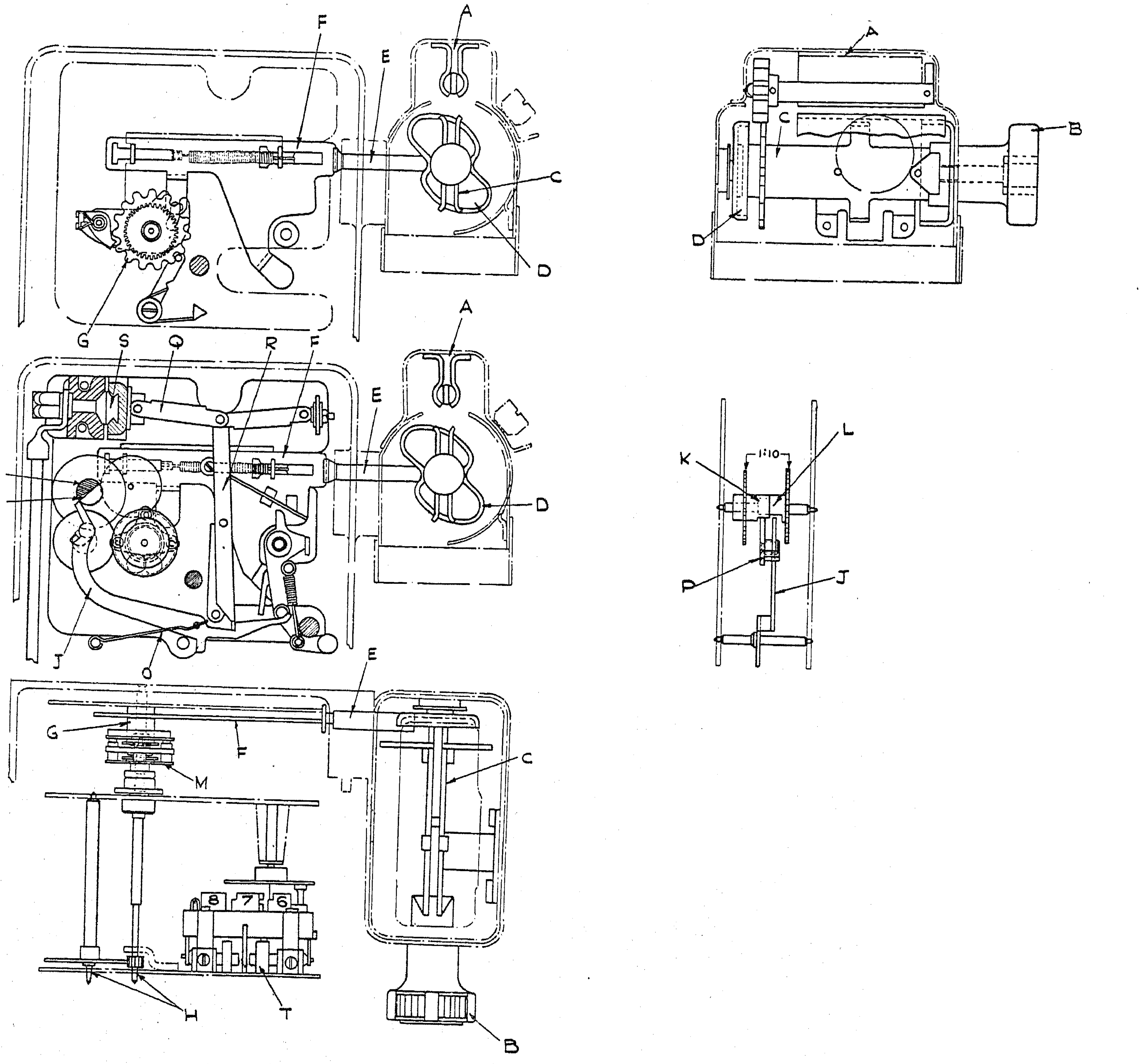

Fig. 25

In one case where the treasury department is responsible for the collection, the lock is actually fixed before the meter is tested. It is evidently desirable for the meter to be separated from the coin mechanism and coin box, and also, from the point of view of meter accuracy, that the division should be sealed against the entry of foreign matter.

Example of modern meter.

The meter shown in Fig. 25 is an example of a modern type. The coin test makes use of the diameter and rigidity of the coin. The aperture A will not admit oversize coins, whilst a small coin drops through the coin mechanism into the box. When the correct coin is accepted it forms a transmission piece between handle member B and driven member C which, on rotation of the handle, transmits the motion to the mechanism. This transmission takes place through cam D, push rod E, and slide bar F, and thus imparts motion to the coin side G of the differential. The return motion of the slide bar closes the switch. The differential has now been actuated to the value of one coin, and this is indicated through the planet wheel of the differential on dial H.

It is an advantage for the movement per coin of the tripping spindle to be large. In order to make the coin storage of reasonable amount it is necessary to provide means of storage without reducing the movement per coin. This is achieved by driving, at a much reduced speed, a similar spindle which also controls the movement of the trip lever, final tripping, however, taking place on the fast-moving spindle.

In this meter the trip lever J is controlled in the closed position by the two tripping spindles. One spindle K, whose movement per coin is large, controls the final trip instant of the tripping lever, whilst the other spindle L is slightly displaced and only controls the trip lever after a few coins have been inserted. This spindle acts as a coin storage and its movement per coin can be made small so that the storage will be large. The lever J carries a pivoted pawl P which locks against the spindle when in the closed position, i.e. when resting on the dead-centre position of the tripping spindles, K and L, which are made with flats through the centre-line to allow tripping. The commodity side of the differential is connected through gearing and price-change unit to the meter. When a supply is taken the meter allows the wound spring to drive the gears. The tripping spindle is geared with the differential and is moved toward zero position. When this is reached the trip lever is freed and flies inwards owing to the action of spring O, and allows switch to trip by the collapse of the toggle system.

The switch control in this instance makes use of a double toggle arrangement Q, R, which allows at one end a great pressure between the contacts whilst at the other end, which is controlled by the trip lever, the pressure is extremely small.

The switch S consists of two gaps in series, each being small when open and being urged together under great pressure when closed.

The general arrangement is such that the coin receiver and mechanism, together with coin box, are completely separated from the meter. The following dials are provided to facilitate checking.

Indicator of value to credit (H).

Register of total coin inserted (T).

(3.32). Optional coin mechanism.

Mechanisms which may be actuated by coins of different denominations will now be considered. These have been called " optional coin " mechanisms.

The mechanism must receive any coin of a selected number of different denominations; apply tests; accept or reject; discriminate which denomination; and allow actuation of the coin side of the differential by an amount proportional to the value of the coin, in addition to closing the switch which is common to all prepayment meters.

The discrimination of coins by the mechanism in general takes place on diameter, but there is great variation in the method of actuation which follows.

The mechanism may have one or more coin receivers. In the case where there is more than one some responsibility rests with the consumer in the correct placing of the coin. A separate coin test is provided for every coin to be used. Broadly this method involves a multiplicity of the well-tried single-coin receiver and test mechanisms.

In the case of the meter with one coin receiver and coin test mechanism the coin test and discrimination is in general more complex. Different wheels, cams, or clutches controlling extent of mechanism actuation, are brought into action in accordance with the diameter of coin inserted.

The motion imparted to the mechanism is thus divided into two parts, coin-diameter gauging operation, and differential actuation. Seven examples from actual practice are described below.

More than one coin entrance.

Two coins (*No.* 3 *in Fig.* 26). Tests for maximum diameter of coins take place at the coin entrances which only allow coins below certain diameters to enter. Coins too small in diameter fall through the gauge slots in the platform. The two receivers are so positioned in the sliding member attached to the push button that a full movement of the button gives a motion to the transmission rack proportional to the value of coins inserted. The other end of the rack operates a pinion directly connected to the coin side of the differential.

Single coin entrance.

All examples in Fig. 26, with the exception of No. 3, are of this type.

Two coins (*No.* 1 *in Fig.* 26).—Two pivoted levers mounted in a rotating frame and normally spring-held against a stationary cam take up new positions after rotation, depending upon the diameter of the coin. One or the other of the levers comes into mesh with its corresponding wheel, and the motion is transferred through a sun-and-planet system to the mechanism. With incorrect coin neither lever comes into mesh.

Three coins (*No.* 2 *in Fig.* 26).—A longitudinally-slotted spindle carries two members capable of longitudinal movement but tied as regards radial movement. A coin, on insertion, takes up a position between the two members. When the handle is turned the first sliding member is urged along the spindle by means of a fixed cam, at the same time storing energy in a returning spring. The coin is thus held between the two sliding members, and the second sliding member is urged against its spring along the spindle. The ultimate position of the second sliding member is decided by the diameter of the coin; this positions a cam pack and actuates the mechanism via a push rod.

Two coins (*No.* 4 *in Fig.* 26).—A longitudinally-slotted spindle carries two spring-urged sliding members, one a rod fitted with pin, the other a wheel (A) free as regards radial movement of the spindle.

Turning of the handle allows movement of the pin down the stationary cam-face, and, if there is no coin in the receiver, avoids engagement with the wheel-driving pin. When the handle is rotated with a coin in the receiver the longitudinal movement of the sliding rod is arrested by the edge of the coin and in turn positions sliding wheel so that it meshes with the appropriate wheel of the mechanism. Further rotation of the handle causes engagement of the two pins, thus imparting motion to the differential.

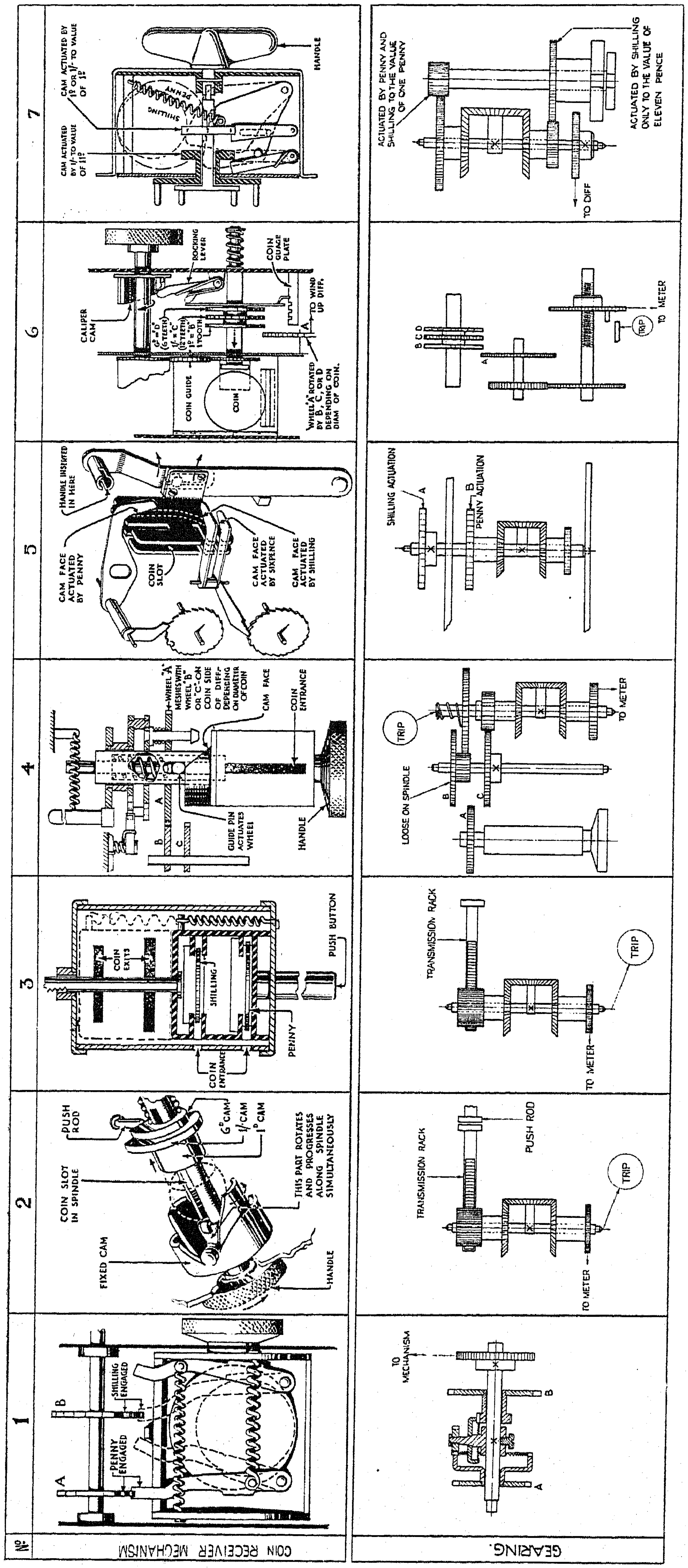
№
COIN RECEIVER MECHANISM
GEARING
1
PENNY ENGAGED
SHILLING ENGAGED
A
B
TO MECHANISM
2
COIN SLOT IN SPINDLE
FIXED CAM
HANDLE
PUSH ROD
6D CAM
1/- CAM
1D CAM
THIS PART ROTATES AND PROGRESSES ALONG SPINDLE SIMULTANEOUSLY
TRANSMISSION RACK
PUSH ROD
TRIP
TO METER
3
COIN EXITS
SHILLING
PENNY
COIN ENTRANCE
PUSH BUTTON
TRANSMISSION RACK
TRIP
TO METER
4
GUIDE PIN ACTUATES WHEEL
HANDLE
WHEEL 'A' MESHES WITH WHEEL 'B' OR 'C' ON COIN SIDE OF DIFF. DEPENDING ON DIAMETER OF COIN
CAM FACE
COIN ENTRANCE
LOOSE ON SPINDLE
TRIP
TO METER
5
CAM FACE ACTUATED BY PENNY
COIN SLOT
HANDLE INSERTED IN HERE
CAM FACE ACTUATED BY SIXPENCE
CAM FACE ACTUATED BY SHILLING
SHILLING ACTUATION
PENNY ACTUATION
6
CALIPER CAM
COIN GUIDE
COIN
WHEEL 'A' ROTATED BY B, C, OR D DEPENDING ON DIAM OF COIN.
ROCKING LEVER
COIN GUAGE PLATE
TO WIND UP DIFF.
B C D
TRIP
TO METER
7
CAM ACTUATED BY 1/- TO VALUE OF 11D
CAM ACTUATED BY 1D OR 1/- TO VALUE OF 1D
PENNY
SHILLING
HANDLE
ACTUATED BY PENNY AND SHILLING TO THE VALUE OF ONE PENNY
ACTUATED BY SHILLING ONLY TO THE VALUE OF ELEVEN PENCE
TO DIFF

Fig. 26

Three coins (*No.* 5 *in Fig.* 26).—The coin is inserted into a coin guide mounted upon a pivoted lever. When the handle is rotated the coin is moved through an arc, actuating one of two further levers. The penny coin moves a lever a certain angular distance, actuating wheel B; shilling or sixpenny coins actuate a second lever which in turn rotates wheel A an amount depending upon the value of the coin.

Three coins (*No.* 6 *in Fig.* 26).—The coin is held between guides and when the handle is turned a rod carrying three wheels is urged against the coin through the medium of a cam and rocking lever. One of three wheels comes into mesh with the mechanism gear wheel, according to diameter of coin. Thus motion is imparted to the differential.

Two coins (*No.* 7 *in Fig.* 26).—A pivoted lever is positioned in accordance with the diameter of the coin inserted, and this in turn actuates one or both of two further levers. These two levers co-act with the two single-toothed cams which are mounted concentrically with the handle. The two cams are directly connected to the summating mechanism. If a penny is inserted pivoted arm is moved to a position where one lever and cam are engaged driving one side of summating gear. With shilling coin both levers and cams are actuated driving both sides of summating gear.

(3.33). Meters for special tariffs.

Probably the first special-tariff meter was that designed to meet the case where separate circuits are used for lighting and power. Of course, two separate meters may be used as mentioned in Section (3.2), but generally this is an inconvenience, and prepayment meters having two measuring elements or a single measuring element with two current windings were used. The former necessitated two price-change units and a means of summating the two motions before they were passed to the differential of the mechanism. The latter does not call for anything special, other than the current windings. In both cases an increased-capacity switch may be required.

Meters for use under sub-section (3.24), where change-over has to be made from one price to another, present the problem of how this mechanical change is to be effected. The possible ways are: Change of meshing of wheels, change of clutches, use of sun-and-planet system with pawls, and ratchets and wheels where fastest wheel drives.

Fixed-charge collectors mentioned under sub-section (3.25) are not strictly electrical prepayment meters because they do not measure any electrical quantity but merely open a switch under the influence of a time device. They may embody a variable-charge unit which is described in the section dealing with fixed-charge meters.

For collecting revenue under a tariff of the fixed-plus-running charge type many schemes have been evolved. Early amongst these was that of making a meter register at a constant rate with no current flowing. This was generally known as the "shunt running" method. It necessitated some provision in the mechanism to take account of arrears.

Then there is the method where, at the beginning of a quarter, the mechanism is set a number of coins in arrears and these have to be inserted before the switch is closed and a supply obtained.

Another arrangement is that in which a high price per unit is charged for so many units, and the remainder at a low price. This meter is sometimes used for the collection of fixed charges, the difference in price multiplied by the number of high-rate units constituting the fixed charge.

A further, and possibly more favoured, method is that where account of the fixed charge takes place constantly without reference to, and completely independent of, consumption. The problem here is to take account of the unit consumption, which of course is discretional, plus the debiting of the constant charge.

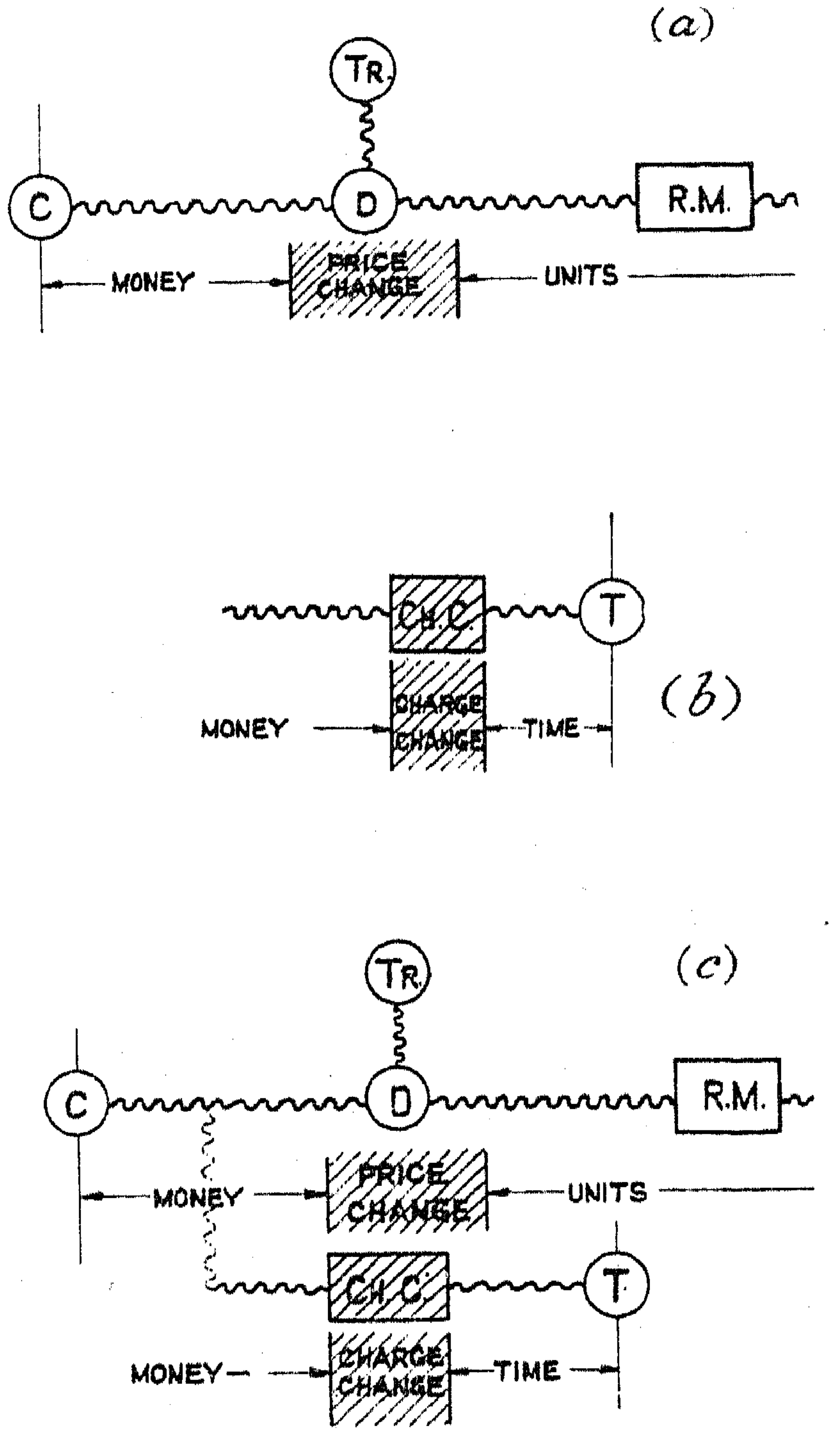

Fig. 27

From the line diagram (Fig. 27*a*) it will be seen that from (C) to the price-change unit the motion is proportional to money. From price-change unit to the meter the motion is proportional to units. The differential, storage, and trip, will be in either value, depending upon their position with respect to the price-change unit.

Referring to Fig. 27(*b*), the motor rotation represents time. A charge-change unit is introduced and converts the motion to money value. From Figs. 27(*a*) and 27(*b*) it is obvious that the motor unit can only be joined to the prepayment mechanism on the money side of the price-change as shown in Fig. 27(*c*).

Fig. 28 shows two methods of performing this operation, one with the price-change on the coin side of the differential, and the other with the price-change on the meter side of the differential. In both cases the motions are connected on the money side of the price-change, as previously mentioned, but in the former case the motions are subtracted, whilst in the latter the motions are added.

Fig. 29 shows the arrangements of seven examples from actual practice. Nos. 1, 2, 3, 5, 6, and 7, belong to the first method, and No. 4 to the second method.

The usual method of connecting the motions is by a sun-and-planet system, but in one case (No. 6, Fig. 29) this is carried out in a different manner. Owing to the comparatively high speed of the motor a large gear reduction is necessary, and use is made of the fact in this case. It consists of two sun wheels but only one pinion gearing in the same plane. One sun wheel has, say, n teeth, and the other has $n - 1$ teeth. The motor drives the planet pinion, and the meter drives one of the sun wheels; the summation taking place on the second sun wheel. From Fig. 30 it will be seen that if the motor drives the pinion one revolution round the main spindle whilst the meter is stationary, the summation wheel will rotate 1 tooth. Hence summation and gear reduction is obtained simultaneously.

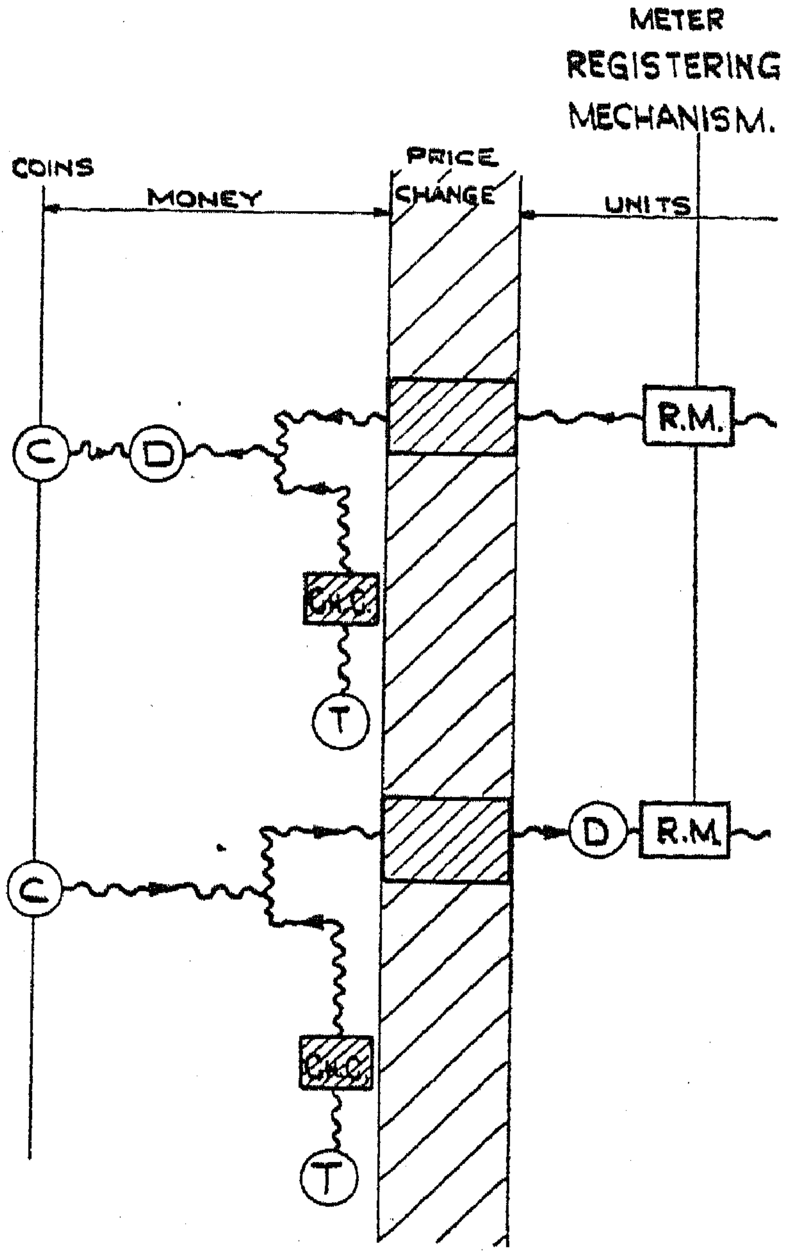

Fig. 28

An additional feature which must be provided in the mechanism is a method of holding out the switch under the constant debit drive of the motor; this occurs when the consumer has not taken current for some time. Referring to No. 4 in Fig. 29, it will be observed that the motor subtracts constantly from the coin-inserted side of the mechanism. In this case if there are no coins standing to credit the motor stores energy in a spring, the movement of the spring representing debit value. The other end of the spring is released by an amount proportional to the number of further coins inserted.

When these meters were first introduced the time unit was a variable-speed motor of the Ferraris-drive type, the variation in charge being obtained by a change in motor speed. This type has been practically superseded by the synchronous-motor type, embodying a charge-change mechanism which permits a variation in price to be more easily carried out.

The provision of these change units has resulted in several ingenious devices which call for some comment. The first requirement is a variable-speed transmission over as large a range as possible and with change steps as small as possible. So far as the authors know this has not been achieved, as, in most examples, for a constant distance travelled by motor only a portion is transmitted to the mechanism, the remainder being idle. This ratio of useful to idle time of transmission does not occur in one cycle covering the whole period of time between collections, but is split up into many cycles for the following reasons:—

(1) The value of charge per coin has to be constant.

(2) Charge has to be proportional to period between collections.

Example No. 1 (*Fig.* 29).—The constant turning motion of the motor is converted to a reciprocating motion and oscillates a toothed member which forms one side of a friction drive. The other side, which is also a friction-drive device, is oscillated between two stops the distance between which is adjustable. The summating wheel is driven forward by an amount that differs from the backward drive due to locking and unlocking of the friction members to the summating wheel as it meets the stops.

Example 2.—The rotary motion drives a screw into a stationary nut until the driving member loses mesh as a result of the longitudinal motion of the screw. The screw now returns under the influence of stored spring energy. The price is altered by changing the starting positions of the screw through the medium of the nut, which carries a price dial.

Example 3.—The motor rotary movement actuates a rocking lever in one direction; this is returned by spring energy. The rocker is geared and drives a uni-directional train which gives a forward drive in both directions of motions to a further wheel system. A change in price is achieved by altering the zero position of the rocking lever.

Example 4.—The motor drives a lever carrying a friction-controlled pawl. Two stops are employed, one fixed and the other adjustable, which effects the change in price. Upon rotation, the pawl is knocked into mesh with the ratchet wheel and causes it to rotate until the pawl is disconnected by the other stop. The cycle is repeated continuously.

Example 5.—A motor-driven wheel carries a pawl near its periphery. The pawl engages with a ratchet wheel when actuated by the adjustable cam B, which effects change in price. Upon further rotation the pawl is disconnected by the pin A. The ratchet wheel is directly connected to the summation gear.

Example 6.—The motor drives a gear which in turn drives two wheels on opposite sides of its centre. These wheels carry pawls which mesh and drive two further wheels when the pre-set cam permits. Two cams, one fixed and one adjustable, are fitted to each further spindle. The two resultant motions are summated.

Example 7.—A ratchet wheel is intermittently driven by a lever carrying a ratchet pawl. This lever receives its forward motion from a second lever (which is continuously driven by the motor), and returns to its zero

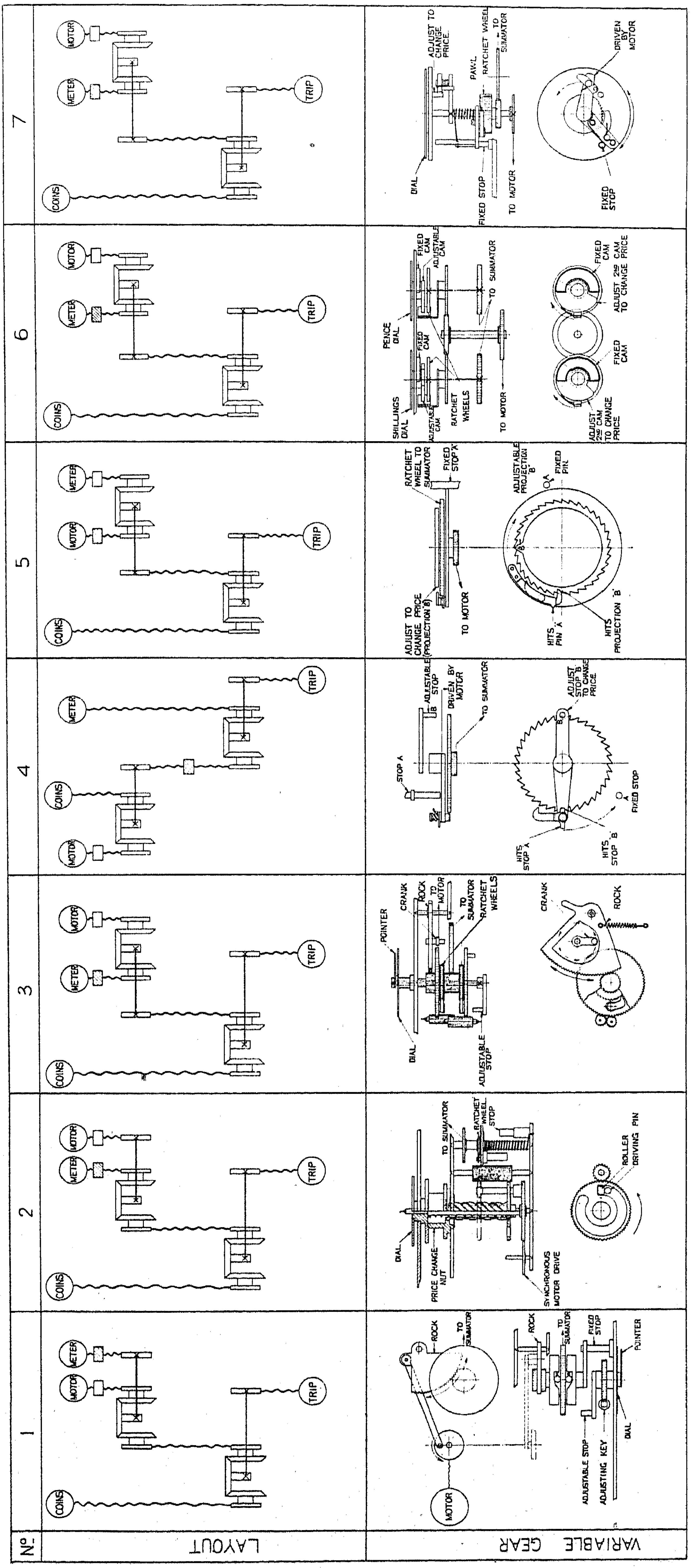
Nº
LAYOUT
VARIABLE GEAR
1
2
3
4
5
6
7
COINS
MOTOR
METER
TRIP
ROCK
TO SUMMATOR
FIXED STOP
POINTER
ADJUSTABLE STOP
ADJUSTING KEY
DIAL
RATCHET WHEEL STOP
PRICE CHANGE NUT
SYNCHRONOUS MOTOR DRIVE
ROLLER DRIVING PIN
CRANK
TO MOTOR
RATCHET WHEELS
STOP A
ADJUSTABLE STOP
DRIVEN BY MOTOR
ADJUST STOP B TO CHANGE PRICE
FIXED STOP
HITS STOP A
HITS STOP B
RATCHET WHEEL TO SUMMATOR
FIXED STOP 'A'
ADJUSTABLE PROJECTION 'B'
FIXED PIN
ADJUST TO CHANGE PRICE (PROJECTION B)
HITS PIN A
HITS PROJECTION 'B'
SHILLINGS DIAL
PENCE DIAL
FIXED CAM
ADJUSTABLE CAM
ADJUST 2ND CAM TO CHANGE PRICE
ADJUST TO CHANGE PRICE.
PAWL
RATCHET WHEEL
DRIVEN BY MOTOR
FIXED STOP

Fig. 29

stop under spring influence. The extent of the forward drive is controlled by means of an adjustable stop on the dial.

The fixed charge may also be collected by the installation of a coin device in conjunction with a standard prepayment meter. It may be of the type requiring a lump-sum payment before the switch can be closed, or it may be of the gradual type. In both cases two separate coin receivers are needed.

Another mechanism provides for the collection of revenue under two different price rates, according to the rate of consumption. With a low consumption the price is high, and vice versa. The load-sensitive relay which changes the price-change train may consist of an attraction electromagnet in the main current circuit working against an adjusted spring, or may consist of a complete wattmeter element the moving part of which works against an adjusted spring.

Another special application is the hotel prepayment meter which is so arranged that it may be reset to zero, i.e. any credit may be cancelled manually by turning the differential to zero by means of a separate key.

Some of the above-mentioned features may be used in combination; an example is the two-rate fixed-charge prepayment meter.

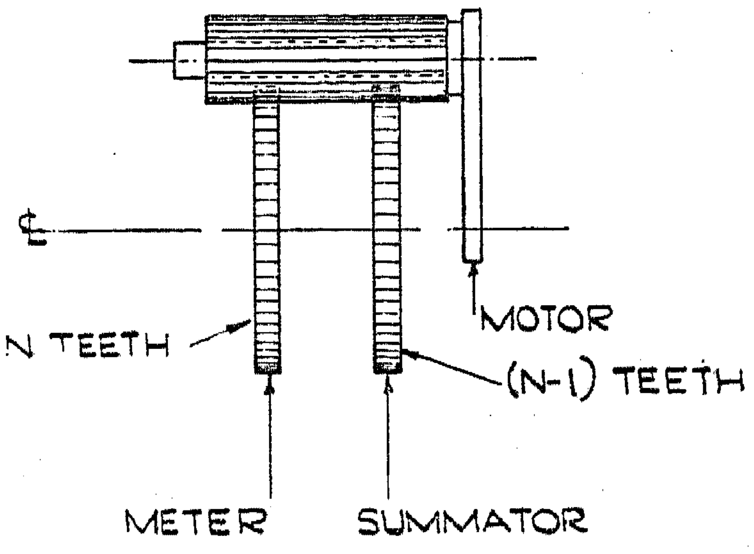

Fig. 30

(3.34). Performance.

The feature of performance which is probably of greatest importance is the delivery of correct value for money inserted, both for number of coins and for each individual coin. In practice the units supplied per coin vary, and the average over a large number of coins is incorrect. The variation is in general cyclic, and may arise from various points in the mechanism and meter gearing. The average error is in general due to the effect of the mechanism upon the meter accuracy.

The practice when looking for these errors is not to measure the actual number of units per coin but to take the meter reading as the criterion of the units. This leaves out all the errors arising from the effect of mechanism upon meter, and some of those due to meter gearing. The units per coin so obtained will be referred to as " the apparent units per coin."

The arrangement shown in Fig. 31(*a*) symbolizes a prepayment meter in which there is unassisted gearing and progressive trip, i.e. one in which the tripping movement starts before the actual instant of trip. The following consideration has been divided into three parts, gearing, tripping mechanism, and effect on meter.

Gearing.

It will be seen that backlash does not affect the accuracy of " apparent units per coin," because it is taken up equally when inserting coins and when running them out. The exception is when the backlash referred to trip is greater than the motion of the latter per coin. This is evident from Fig. 32, where (*a*) shows tooth thrust faces whilst meter only is running, and (*b*) the same when coins are inserted. It will be seen that there is a change-over from one face to the other and that the backlash is taken up a constant amount under each condition. The meter has to drive all the gearing and will be affected. Vibration may result in an alteration of position of the differential planet system. When the value of one coin has been practically consumed, the switch-tripping mechanism commences to operate and a further load is thrown on the meter. It tends, however,

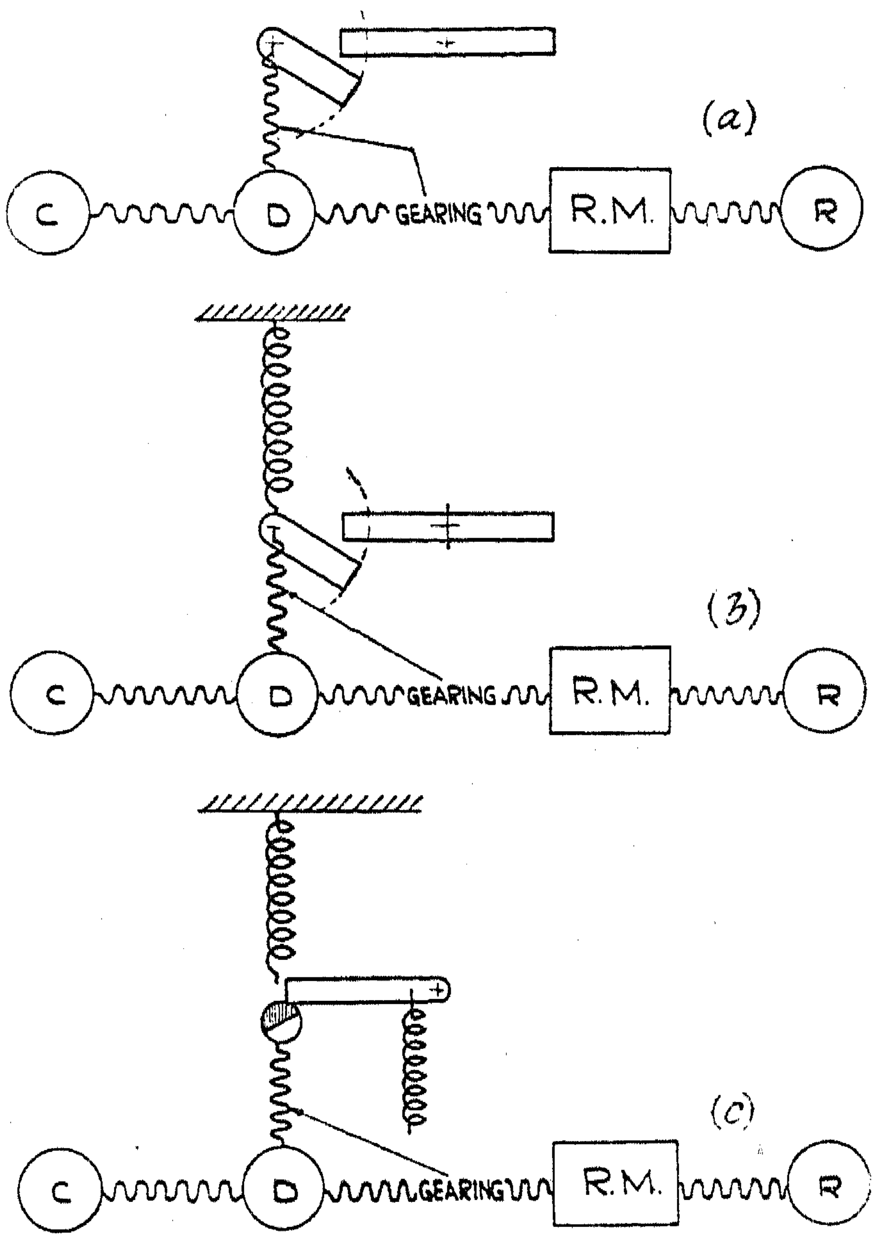

Fig. 31

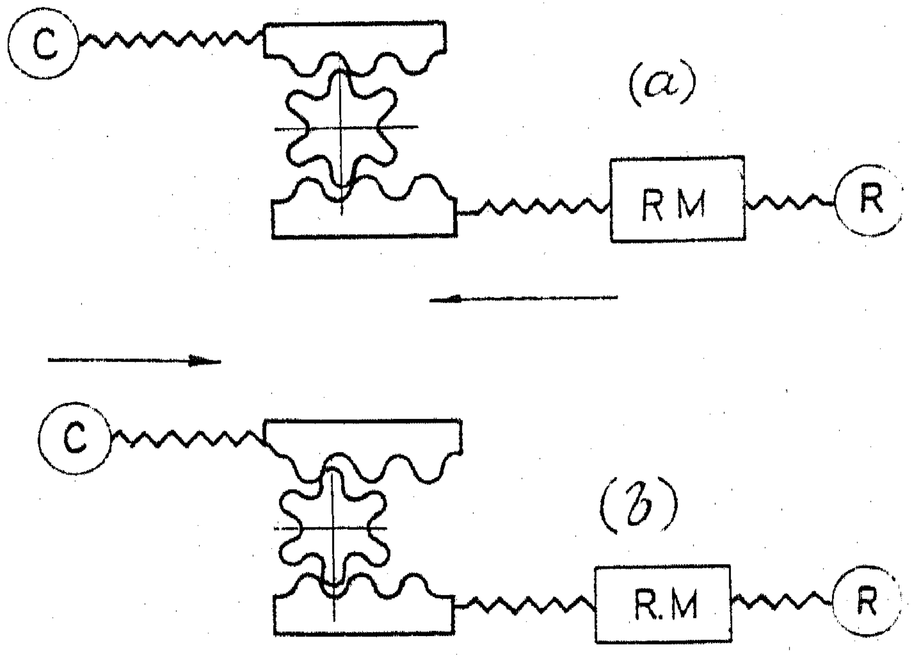

Fig. 32

(*a*) Meter driving towards trip also applies to trip instant.
(*b*) Insertion of coin.

to make the mechanism more stable near tripping point under vibration conditions.

The mechanical load on the meter may be reduced by the use of a spring on the spindle carrying the planet system of the differential [Fig. 31(*b*)], which acts in a direction tending to trip the switch. Additional load occurs at the time of trip. For obvious reasons the spring torque cannot be made so large as to drive right down from differential to meter disc (it would result in meter errors), and therefore the spring drives only part of the way, i.e. until a point is reached where the reduced spring driving torque (due to spindle ratios and spindle friction) is exceeded by spindle friction. From this point onwards the meter is doing the work. Between the two is a wheel which alternately comes under each control and which for lack of a better name has been termed the "transition" wheel.

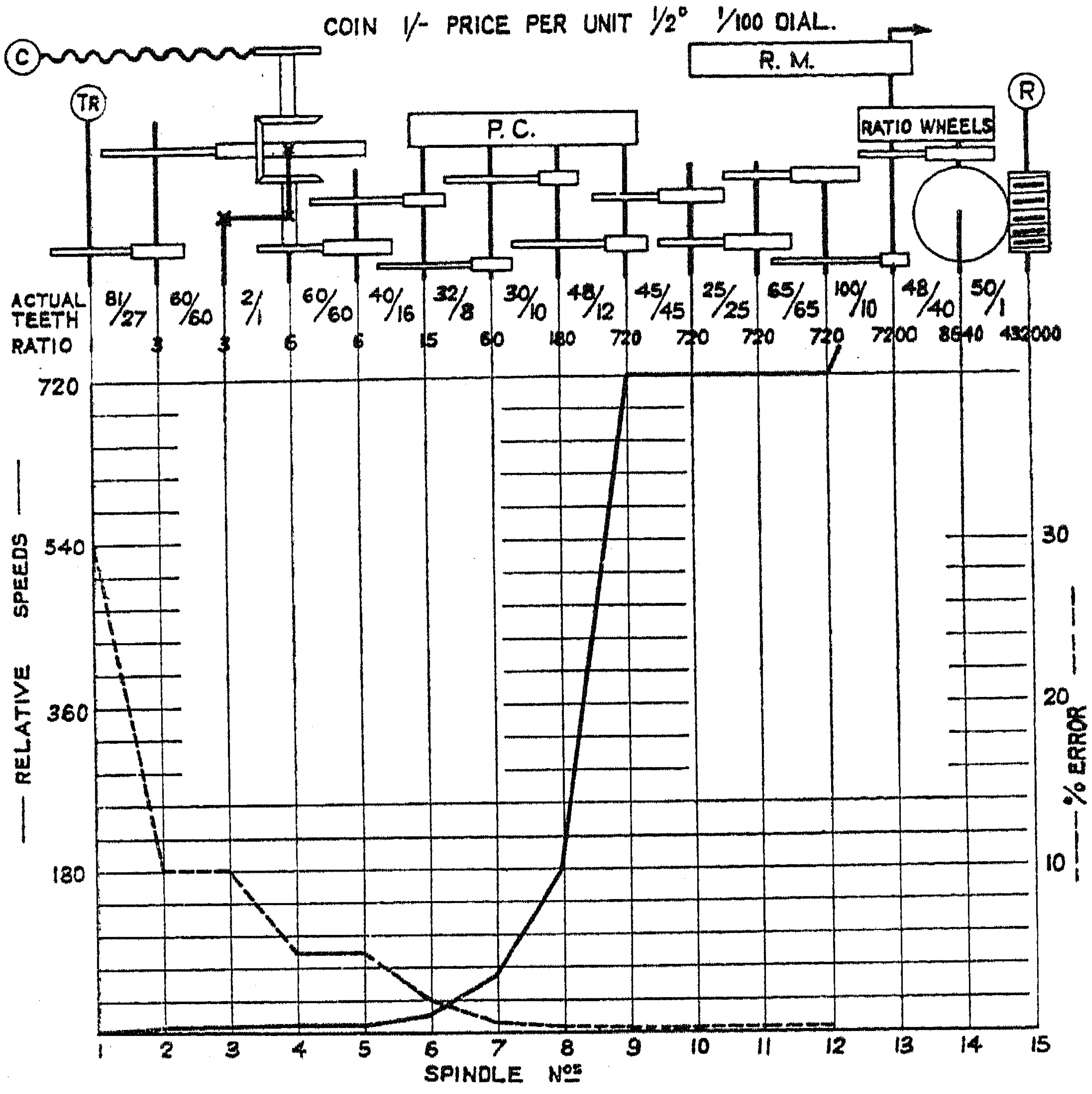

Fig. 33

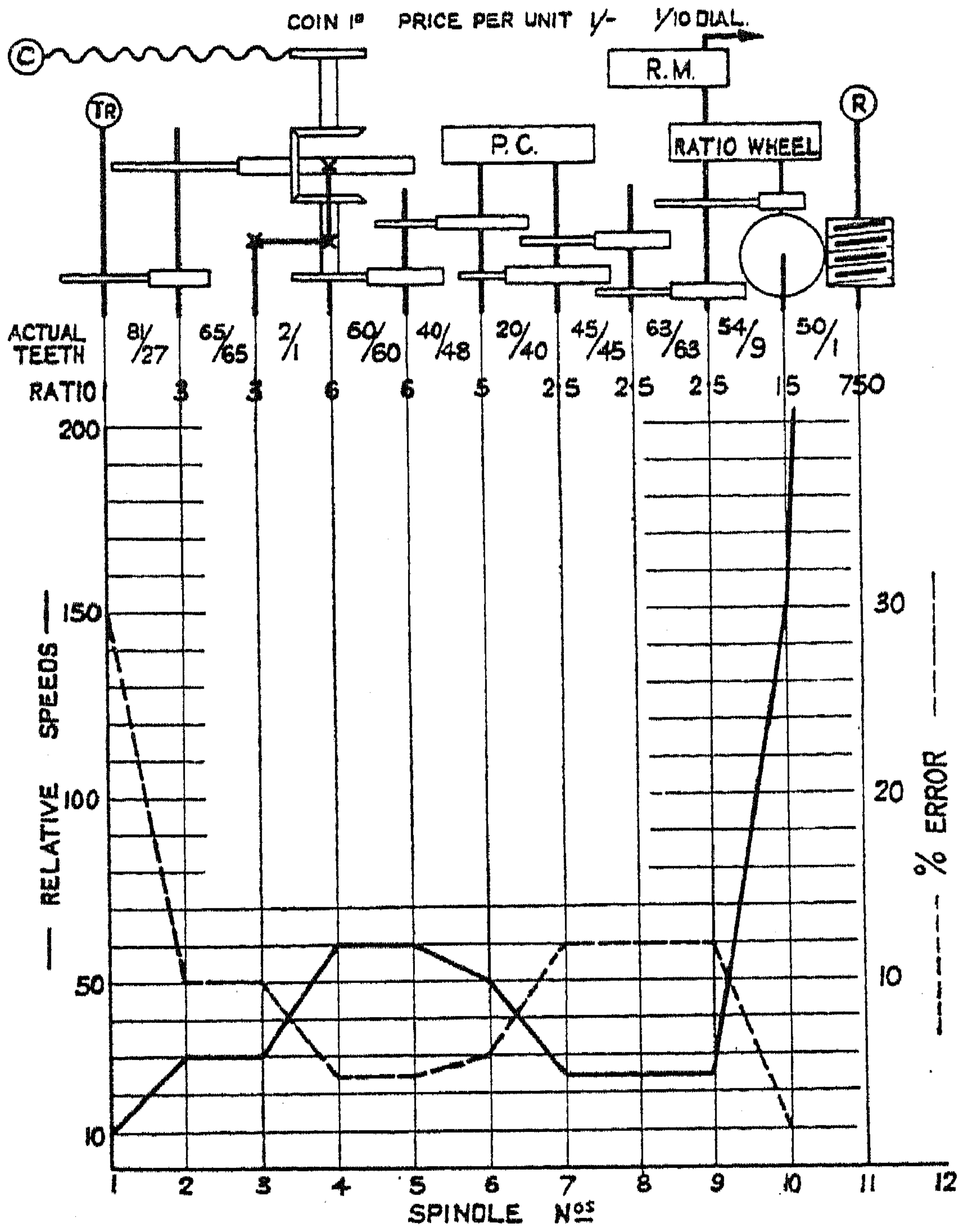

Fig. 34

The position of the transition wheel comes nearer to the differential at the time of tripping because the spring torque through the gear is reduced owing to some of the torque being used in tripping; also the load on the meter increases because more wheels are being driven.

The error introduced by the idle movement of the transition wheel owing to change of control of the latter may be expressed as a percentage of the angular motion of tripping spindle per coin. Thus

$$\text{Percentage error} = \frac{\begin{array}{c}\text{(Idle movement of transition wheel,}\\ \text{referred to tripping spindle)} \times 100\end{array}}{\begin{array}{c}\text{Movement of tripping spindle per}\\ \text{coin}\end{array}}$$

The importance of this expression can be verified by the examples shown in Figs. 33 and 34.

Fig. 33.

Here we are considering the case of a shilling-coin meter, the price per unit being ½d., and the smallest dial on the meter train reading 1/100 unit per division. A schematic view of the gear wheels between the trip spindle and rotor is shown. Each spindle is considered in turn as becoming the transition wheel, and the error introduced by an assumed shake of 3·6° is shown.

Finally the percentage error per spindle is obtained from the above expression and is plotted against spindle number. On inspection the error becomes greater as the gear ratio becomes smaller. The maximum error of 30 per cent occurs on spindle No. 1 as this has the smallest ratio.

Fig. 34.

This is the case of a 1d.-coin meter, the price per unit being 1s., and the smallest dial on the meter train reading 1/10 unit per division. The maximum error is 30 per cent, and this occurs on spindle No. 1 (having the lowest ratio).

Between these extremes several cases have been worked out and are detailed in Tables 1 and 2. The additional load at or about the tripping time is thus undesirable from the point of view of units per coin and may be avoided completely by the use of the tripping arrangement shown in Fig. 31(*c*).

Tripping Mechanism.

A tripping mechanism should possess the following qualities:—

(*a*) Impose constant load.

(*b*) Trip always at exactly the same position.

If the imposed load is not constant the position of the transition wheel will change and result in errors as explained previously. The best way of overcoming this is probably to use a dead-centre action.

Effect on Meter.

Many references have been made in considering the gearing to the effect of the mechanisms upon the accuracy of the meter.

Table 1

(Assuming error of 3·6° per spindle, coin 1s.)

Spindle No.	Percentage error and ratio											
	1/100 dial						1/10 dial					
	½d.		2d.		1s.		½d.		2d.		1s.	
Trip 1	30	1	30	1	30	1	30	1	30	1	30	1
2	10	3	10	3	10	3	10	3	10	3	10	3
Diff.(Planet) 3	10	3	10	3	10	3	10	3	10	3	10	3
Diff. (Sun) 4	5	6	5	6	5	6	5	6	5	6	5	6
5	5	6	5	6	5	6	5	6	5	6	5	6
6	2	15	8	3·75	6	5	2	15	8	3·75	6	5
7	0·5	60	2	15	1·5	20	0·5	60	2	15	1·5	20
8	0·16	180	0·66	45	0·5	60	0·16	180	0·66	45	0·5	60
9	0·04	720	0·165	180	1·0	30	0·04	720	0·165	180	1·0	30
10	0·04	720	0·165	180	1·0	30	0·04	720	0·165	180	1·0	30
11	0·04	720	0·165	180	1·0	30	0·04	720	0·165	180	1·0	30
12	0·04	720	0·165	180	1·0	30	—	—	—	—	—	—
13	0·004	7 200	0·0165	1 800	0·1	300	—	—	—	—	—	—
14	—	8 640	—	2 160	—	360	—	4 320	—	1 080	—	180
Rotor 15	—	432 000	—	108 000	—	18 000	—	216 000	—	54 000	—	9 000

Table 2

(Assuming error of 3·6° per spindle, coin 1d.)

Spindle No.	Percentage error and ratio											
	1/100 dial						1/10 dial					
	½d.		2d.		1s.		½d.		2d.		1s.	
Trip 1	30	1	30	1	30	1	30	1	30	1	30	1
2	10	3	10	3	10	3	10	3	10	3	10	3
Diff.(Planet) 3	10	3	10	3	10	3	10	3	10	3	10	3
Diff. (Sun) 4	5	6	5	6	5	6	5	6	5	6	5	6
5	5	6	5	6	5	6	5	6	5	6	5	6
6	2	15	8	3·75	6	5	2	15	8	3·75	6	5
7	0·5	60	2	15	12	2·5	0·5	60	2	15	12	2·5
8	0·5	60	2	15	12	2·5	0·5	60	2	15	12	2·5
9	0·5	60	2	15	12	2·5	0·5	60	2	15	12	2·5
10	0·5	60	2	15	12	2·5	—	—	—	—	—	—
11	0·05	600	0·2	150	1·2	25	—	—	—	—	—	—
12	—	720	—	180	—	30	—	360	—	90	—	15
Rotor 13	—	36 000	—	9 000	—	1 500	—	18 000	—	4 500	—	750

Tripping may not always occur at the same position, as a result of "shake" in the bearings B and C (Fig. 35). It therefore follows that the "shake" effect, stated as a ratio of the peripheral distance of part A to the peripheral distance of part A per coin, should be small.

Any work that the meter might be called upon to do can be divided into two parts, i.e. driving the gears and tripping the switch. Referring again to Fig. 31(*a*), the meter must perform the whole of the work. In most cases the effect upon the meter will be large.

In case (*b*) a spring has been introduced to relieve the meter of the work of driving the gears of the mechanism. At the instant of tripping the meter will be required to supply the additional work necessary to trip the switch. The change-over will take place as previously described, and therefore the meter will drive more gears. The meter accuracy will be affected, depending upon the value of the tripping load, but in general to a smaller extent than in case (*a*).

In case (*c*) a spring has been introduced to relieve the meter, and the trip is of the dead-centre type. This will result in a constant load, and it is possible for the spring to supply the work for driving the mechanism up to the point of gearing with the meter train. In this way the meter will do no more work than the simple quarterly type.

(3.4). Fraud and its Prevention

Frauds may be sub-divided according to the part of the meter directly affected, as follows:

(3.41). Coin mechanism.
(3.42). Measuring device.

(3.41). Coin mechanism.

(*a*) False coin.
(*b*) True coin afterwards withdrawn.

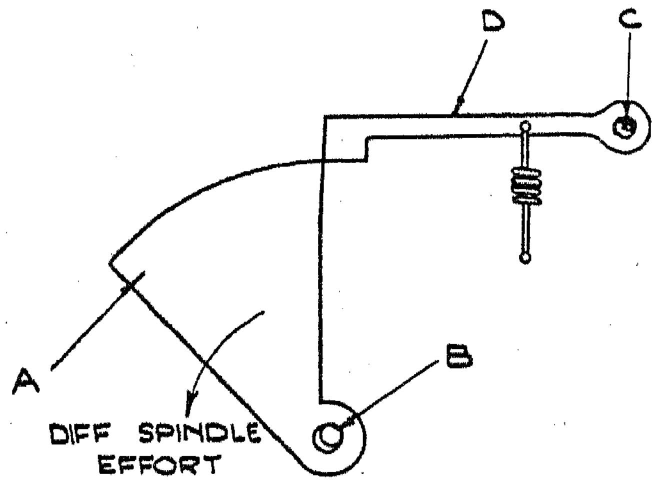

Fig. 35

(*c*) Distortion or actuation of vital parts by insertion of implement through coin receiver.
(*d*) Withdrawal of money from box.

(*a*) *False coin.*—A washer or metal disc may happen to pass the coin test and consumer obtain a supply to the value of the proper coin. This type of fraudulent operation is detectable by means of the dial reading and the presence of a token which will pass the coin test.

Another method is the use of tokens made from ice; after operation of the mechanism these leave little trace. All these frauds are detectable with reference to the dials, but it is often difficult to obtain refund of the money owing to various complications.

(*b*) *True coin afterwards withdrawn.*—The object behind this fraud is to prevent the coin being released into the coin box and to allow its withdrawal. The first method is to attach a thread to the coin and withdraw it after each operation. One method of prevention is to interpose between the coin slot and the coin holder a shaft with progressive motion round which the thread would become wound and thus prevent withdrawal of the coin.

The coin may be jammed in the holder by the use of a wedge or more than one coin, which allows continued actuation, the coin or coins being subsequently withdrawn with tweezers. The cure is a stop in the path of the coin, or a coin-operated member which must return to zero every cycle, or a combination of these.

(*c*) *Distortion or actuation of vital parts by insertion of implement through coin receiver.*—These may be divided according to whether or not the handle is used.

The first is the direct operation of the " coins side " of the differential by means of wire or other implement inserted through the coin receiver. This may be prevented by masking the vital part.

The second is the removal or permanent distortion of vital parts so that the handle may be operated subsequently without a coin. Here again masking is the solution.

The third method is where the handle and pawls, etc., are manipulated together. The cure is to arrange for the coin slot to be closed immediately the handle is turned, and in any case before the mechanism is operated.

(*d*) *Withdrawal of money from box.*—The withdrawal of money from the box without the withdrawal being in any way facilitated by the mechanism is not considered because it is not peculiar to meter mechanisms. The method of fraud which is peculiar to prepayment mechanisms is that in which money is withdrawn from the coin box through the coin receiver.

Roughly speaking, there are two coin entrances through which the coin must be withdrawn, and the fraud may be prevented by arranging that when one is open the other is closed, and vice versa.

(3.42). Measuring device.

Frauds applicable to measuring device when associated with coin devices consist of those in which an implement or foreign matter is introduced through the coin receiver. This is discussed by A. Pestel.*

The trouble can be minimized by the use of shields, and can be eliminated completely by housing the coin receiver in a separate compartment.

Frauds are of particular importance in certain foreign countries because the people are more inclined to attempt fraud and because it is often necessary to catch them in the act in order to satisfy legal requirements.

(3.5). Foreign Practice

One of the most outstanding points which affect the use of coin mechanisms is the psychological reaction of the peoples concerned. For example, the authors believe that in Canada and the United States there is a definite objection to prepayment.

In general the survey of foreign practice seems to indicate that prepayment meters are not used to any great extent.

A few are used in Holland (by lower and part of middle class), Austria, Switzerland, New Zealand, and Italy. In the last-named case their use is confined to isolated towns and is decreasing. They are not used in Denmark, France, and Portugal. In the case of Belgium a deposit guarantee is generally required, which feature eliminates the greatest advantage possessed by the use of prepayment meters.

The reason given in Spain for not using prepayment meters is the greater cost of such meters as compared with quarterly meters.

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* See Reference (5).

In two foreign countries only can the authors find evidence of the use of two-part tariff operated by prepayment meter. In Italy and Holland a small number are used. Similarly with tokens; these are sometimes used in Italy and Finland and can be purchased from shops.

The manufacture of this class of meter appears to be carried out in a number of countries, notably Denmark, Holland, Austria, Germany, and Switzerland. No evidence has come to light regarding the use of optional-coin electricity meters.

The consideration of foreign practice resolves itself somewhat into giving reasons why prepayment meters are not used to any great extent. In many cases the reason is psychological, but there is also another reason. The legal requirements relating to prosecutions in a number of countries are such that a person must be caught in the act of defrauding. The difficulties of doing this are obvious, and in consequence prepayment meters are not favoured.

(3.6). Testing

Testing can be divided into "type" and "routine"; the latter consists of modifications to certain of the type tests.

The main points are:—

(3.61). Coin limits (denomination).
(3.62). Susceptibility to frauds.
(3.63). Coin-box capacity.
(3.64). Reading of coins indicator and coins register.
(3.65). Switch.
(3.66). Stability under vibration and/or shock.
(3.67). Apparent units per coin.
(3.68). Effect on meter accuracy.

(3.61). Coin limits (denomination).

Here we are concerned with the fact that the mechanism should operate with the correct coin and no other (both type and routine test).

The limits of the coin in respect of the qualities outlined under sub-section (2.12) must first of all be decided and standards representing the extreme limits established. These or reliable sub-standards will then be used during the test, e.g. where operation takes place on diameter a test is made with coins of maximum and minimum diameters.

(3.62). Susceptibility to fraud.

This is generally a type test only and consists in an examination of the mechanism for susceptibility to fraud under all the items under Section (3.4).

(3.63). Coin-box capacity.

This is generally a type test only and rather obviously consists in the insertion of coins until the box is full and the insertion of further coins rendered impossible. The test should be repeated several times, as, owing to difference in "piling," the reliable maximum capacity may not be obtained at the first attempt.

(3.64). Reading of coin indicator and coin register.

This is a combined type and routine test and consists merely in checking the indications of the credit indicator and the reading of the coin register against the coins inserted.

(3.65). Switch.

This again is both a type and routine test. The type test will consist of:—

(*a*) Voltage-drop.
(*b*) Heating.
(*c*) Breakdown capacity.
(*d*) Life test.
(*e*) Closure on coin insertion.

Items (*a*) and (*e*) will be adopted as routine tests.

(3.66). Stability under vibration or shock.

This is a type test only. Engineers have been known to apply this test by fixing a meter on a wall and noting the effect when a door is "banged." Whilst this is a rough-and-ready practical test it lacks uniformity. The tests used by the authors are:—

(*a*) *Vibration.* The meter is attached to apparatus in which vibrations of various frequencies and magnitudes may be set up by means of electromagnets in any one of three directions.

(*b*) *Shock.* The meter is subjected to mechanical shocks by means of apparatus which merely consists of a pivoted lever carrying a weight at its extremity, i.e. similar to an impact-testing machine.

(3.67). Apparent units per coin.

This again is both a type and routine test. The way that is naturally suggested is to insert a coin and to run the meter electrically, noting the change in meter reading.

A usual tolerance in the apparent units per coin is ± 3 per cent, and a common practice is to test several individual coin insertions and several coins together. Where this method is considered too lengthy the test may be carried out by hand by simply rotating the meter train; special means for facilitating this are generally provided. The method has certain disadvantages, notably that excessive force may be applied, and perhaps the best way is a compromise in which the gearing is run out first by hand and then tripped electrically.

(3.68). Effect on meter accuracy.

This has normally been determined in type tests and shows its maximum effect on low loads. In the event of it being excessive it is shown in the normal electrical test of the meter element. During type tests it should be carried out first with the switch closed and then with the switch about to open, so that the possible additional load may show effect. Meters for special tariffs necessitate tests additional to those considered above.

(3.7). Reason and Justification of this Method of Revenue Collection

The prepayment meter is, in general, suitable for the consumer of small means. This becomes evident on considering its advantages and disadvantages.

The advantages and disadvantages from both the consumer's and the supply authority's point of view are as follows:—

(3.71). Advantages.

(*a*) *Consumer.*

(1) He pays in small amounts.
(2) Broadly speaking, he can pay when convenient.
(3) He cannot run into debt.
(4) He has an incentive to check and control running costs.

(*b*) *Supply Authority.*

(1) Less accounting (no bills).
(2) Reduction of bad debts.
(3) Special applications (hotels, etc.).

(3.72). Disadvantages.

(*a*) *Consumer.*

(1) Pays extra per unit.
(2) Supply is interrupted without adequate warning.

(*b*) *Supply Authority.*

(1) Reading and collecting cost increased.
(2) Increased maintenance necessary.

Payment in small amounts, whilst of little importance to a consumer of means, is of great importance to the consumer of small means and may be the deciding factor for or against taking an electricity supply.

In those homes where each item of expenditure has to be very carefully budgeted and only so much allocated to electricity supply, that amount may be inserted in the meter on receipt of the weekly income.

A person cannot run into debt, except in the case of fixed-charge meters, as is possible in other cases, unknowingly.

Since periodic visits to the meter have to be made it is more frequently brought to mind and provides an incentive to check the running costs.

Several disadvantages are present, one of which is that meter charges are higher and are included in the price per unit. Another is that the supply is cut off generally without adequate warning; this may be a source of annoyance.

From the supplier's point of view the reading and collecting costs are obviously increased, together with increased maintenance. Several of these points were laid down as early as 1907.*

(3.8). Conclusion.

Despite the fact that the idea of coin mechanisms is comparatively old, very few general principles appear to have been laid down.

It has been found possible to state the broad principles under which coin mechanisms of whatever type operate.

The importance of automatic tests of coins varies with the application of the mechanism. In vending machines it is of great importance, while in electricity meters it is of somewhat less importance. Diameter is the most suitable property of coins, either for testing for correct coin or discrimination between coins.

In electricity meters tariffs affect mechanism design through the demand for greater flexibility to meet frequent changes in magnitude and type of tariff, e.g. price per unit and fixed charge.

Excluding the actual automatic tests on the coin and the switch performance, the important features are consistent and accurate units per coin, and effect on meter accuracy. In this respect the ideal state of affairs would be for the spring provided to assist the gearing to be effective at all times (including tripping) up to the train, in addition to some device to prevent transition-wheel effect. The meter would then do no more work than a meter without mechanism, and the accuracy of units per coin would be much improved. Experience has shown that in practice either one is capable of considerable improvement at the expense of the other.

Referring to frauds, the most serious are those which are undetectable unless a person is caught in the act. They are generally frauds in which an implement is introduced to stop the meter.

Prepayment meters are not in great demand in countries other than Great Britain.

Table 3

	Meter Department	Treasury Department	Both
Total	866 880	2 673 403	88 468
Quarterly	609 758	1 901 748	18 343
Prepayments ..	257 122	771 655	70 125
Prepayments as percentage of total prepayment meters (1 098 902) ..	23·4	70·3	6·3

The tests on prepayment meters which have been outlined are fairly simple in character and do not demand very special or costly apparatus to carry them out.

Probably the greatest advantage of the prepayment meter lies in the fact that payment may be made in small amounts, and it therefore provides the best means of promoting the use of electricity amongst people of small means.

Finally the authors wish to thank those firms and individuals who have supplied information, and in particular Messrs. Ferranti, Ltd., for permission to publish the paper.

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* See Reference (6).

APPENDIX I

Coins in Order of Diameter

Diameter	Difference	Coin	Country	Thickness	Shape	Rim	Holes	Serration
in.	in.			in.				
0·593	—	10 ore	Sweden	0·044	Round	Yes	No	No
0·606	0·013	2 annas (1915)	India	0·038	Round	Yes	No	No
0·607	0·001	5 cents	Canada	0·027	Round	Yes	No	Yes
0·669	0·062	25 ore	Sweden	0·051	Round	Yes	No	No
0·705	0·036	10 cents	Hong Kong	0·051	Round	Yes	No	Yes
0·708	0·003	10 sen	China	0·046	Round	Yes	No	Yes
0·710	0·002	10 sen	Japan	0·055	—	—	One	—
0·711	0·001	25 cents	Ceylon	0·056	Round	Yes	No	Yes
0·726	0·015	10 cents	Canada	0·043	Round	Yes	No	Yes
0·746	0·020	10 heller	Austria	0·057	Round	—	—	—
0·751	0·005	¼ rupee	India	0·046	Round	Yes	No	Yes
0·755	0·004	1 cent	Canada	0·060	Round	Yes	No	No
0·762	0·007	10 centavos	Argentine Republic	0·049	Round	Yes	No	Yes
0·763	0·001	4 annas	India	0·049	Round	—	—	—
0·770	0·007	Sixpence	Great Britain	0·065	Round	Yes	No	Yes
0·798	0·018	½ mark	Germany	0·045	Round	—	—	—
0·826	0·028	20 heller	Austria	0·060	Round	—	—	—
0·826	0·000	1 anna	India	0·064	Toothed	Yes	No	No
0·826	0·000	5 lei	Rumania	0·059	Round	Yes	No	Yes
0·828	0·002	½ pice	India	0·043	Round	Yes	No	No
0·830	0·002	100 reis	Brazil	0·071	Round	Yes	No	No
0·831	0·001	10 pfennig	Germany	0·059	Round	Yes	No	No
0·838	0·007	5 cents	U.S.A.	—	—	—	—	—
0·840	0·002	2 annas (1926)	India	0·065	Square (radiused corners)	Yes	No	No
0·843	0·003	20 centavos	Argentine Republic	0·056	Round	Yes	No	Yes
0·847	0·004	20 centavos	Chile Republic	0·047	Round	Yes	No	Yes
0·863	0·016	Pennia	Finland	0·047	Round	Yes	No	No
0·864	0·001	2 cents	Belgium	0·045	Round	Yes	No	Yes
0·866	0·002	50 ore	Sweden	0·063	Round	Yes	No	Yes
0·867	0·001	10 cents (1915)	Belgium	0·069	Round	Yes	No	No
0·870	0·003	10 groschen	Austria	0·067	Round	Yes	No	No
0·872	0·002	10 cents (1903)	Belgium	0·051	Round	Yes	One	No
0·897	0·025	1 franc	Belgium	0·064	Round	Yes	No	Yes
0·902	0·005	5 markkaa	Finland	0·067	Round	Yes	No	Yes
0·904	0·002	1 korona	Austria	0·060	Round	—	—	—
0·908	0·004	25 pfennig	Germany	0·053	Round	—	—	—
0·909	0·001	10 lei	Rumania	0·073	Round	Yes	No	Yes
0·909	0·000	1 peseta	Spain	0·051	Round	Yes	No	Yes
0·911	0·002	20 centavos	Colombian Republic	0·065	Round	Yes	No	Yes
0·912	0·001	1 franc	France	0·063	Round	Yes	No	Yes
0·912	0·000	20 cents	Hong Kong	0·058	Round	Yes	No	Yes
0·919	0·007	20 cents	Straits Settlements	0·065	Round	Yes	No	Yes
0·926	0·007	2½ cents	Holland	0·028	Round	Yes	No	Yes
0·928	0·002	25 cents	Canada	0·063	Round	Yes	No	Yes
0·928	0·000	1 shilling	British West Africa	0·072	Round	Yes	No	Yes
0·935	0·007	1 shilling	Great Britain	0·075	Round	Yes	No	Yes
0·943	0·008	1 markka	Finland	0·071	Round	Yes	No	Yes
0·953	0·010	1 mark	Germany	0·058	Round	—	—	—
0·957	0·004	¼ dollar	Sweden	0·061	Round	Yes	No	Yes
0·989	0·032	1 kroner	Denmark	0·078	Round	—	—	—
0·993	0·004	¼ anna	India	0·053	Round	Yes	No	No
0·994	0·001	200 reis	Brazil	0·074	Round	Yes	No	No
1·022	0·028	5 piastres	Egypt	0·057	Round	Yes	No	Yes
1·026	0·004	8 annas	India	0·076	Round	Yes	No	No
1·029	0·003	1 000 reis	Brazil	0·084	Round	Yes	No	Yes

Coins in Order of Diameter—*continued*

Diameter in.	Difference in.	Coin	Country	Thickness in.	Shape	Rim	Holes	Serration
1·065	0·036	20 lei	Rumania	0·073	Round	Yes	No	Yes
1·100	0·035	1 peso	Chile Republic	0·070	Round	Yes	No	Yes
1·130	0·030	Florin	Great Britain	0·095	Round	Yes	No	Yes
1·185	0·055	10 gramos	Spain	0·066	Round	Yes	No	No
1·185	0·000	10 centimes	France	0·068	Round	—	—	—
1·186	0·001	10 centesimi	Italy	0·074	Round	Yes	No	No
1·206	0·020	1 rupee	India	0·076	Round	Yes	No	Yes
1·213	0·007	1 penny	Great Britain	0·074	Round	Yes	No	No
1·225	0·012	50 cents	Hong Kong	0·081	Round	Yes	No	No
1·280	0·055	Half-crown	Great Britain	0·095	Round	Yes	No	Yes

Coins in Order of Thickness

Thickness in.	Difference in.	Coin	Country	Diameter in.	Shape	Rim	Holes	Serration
0·027	—	5 cents	Canada	0·607	Round	Yes	No	Yes
0·028	0·001	2½ cents	Holland	0·926	Round	Yes	No	Yes
0·038	0·010	2 annas (1915)	India	0·606	Round	Yes	No	No
0·043	0·005	10 cents	Canada	0·726	Round	Yes	No	Yes
0·043	0·000	½ pice	India	0·828	Round	Yes	No	Yes
0·044	0·001	10 ore	Sweden	0·593	Round	Yes	No	No
0·045	0·001	2 cents	Belgium	0·864	Round	Yes	No	Yes
0·045	0·000	½ mark	Germany	0·798	Round	—	—	—
0·046	0·001	¼ rupee	India	0·751	Round	Yes	No	No
0·046	0·000	10 sen	China	0·708	Round	Yes	No	Yes
0·047	0·001	20 centavos	Chile Republic	0·847	Round	Yes	No	Yes
0·049	0·002	4 annas	India	0·763	Round	—	—	—
0·049	0·000	10 centavos	Argentine Republic	0·762	Round	Yes	No	Yes
0·051	0·002	10 cents (1903)	Belgium	0·872	Round	Yes	One	No
0·051	0·000	1 peseta	Spain	0·909	Round	Yes	No	Yes
0·051	0·000	25 ore	Sweden	0·669	Round	Yes	No	No
0·051	0·000	10 cents	Hong Kong	0·705	Round	Yes	No	Yes
0·053	0·002	¼ anna	India	0·993	Round	Yes	No	No
0·053	0·000	25 pfennig	Germany	0·908	Round	—	—	—
0·055	0·002	10 sen	Japan	0·710	—	—	—	—
0·056	0·001	20 centavos	Argentine Republic	0·843	Round	Yes	No	Yes
0·056	0·000	25 cents	Ceylon	0·711	Round	Yes	No	Yes
0·057	0·001	5 piastres	Egypt	1·022	Round	Yes	No	Yes
0·057	0·000	10 heller	Austria	0·746	Round	—	—	—
0·058	0·001	20 cents	Hong Kong	0·912	Round	Yes	No	Yes
0·058	0·000	1 mark	Germany	0·953	Round	—	—	—
0·059	0·001	5 lei	Rumania	0·826	Round	Yes	No	Yes
0·059	0·000	10 pfennig	Germany	0·831	Round	Yes	No	Yes
0·060	0·001	20 heller	Austria	0·826	Round	—	—	—
0·060	0·000	1 korona	Austria	0·904	Round	—	—	—
0·060	0·000	1 cent	Canada	0·755	Round	Yes	No	No
0·061	0·001	½ dollar	U.S.A.	0·957	Round	Yes	No	Yes
0·063	0·002	50 ore	Sweden	0·866	Round	Yes	No	Yes
0·063	0·000	25 cents	Canada	0·928	Round	Yes	No	Yes
0·063	0·000	1 franc	France	0·912	Round	Yes	No	Yes
0·064	0·001	1 anna	India	0·826	Toothed	Yes	No	No
0·064	0·000	1 franc	Belgium	0·897	Round	Yes	No	Yes
0·065	0·001	20 centavos	Colombian Republic	0·911	Round	Yes	No	Yes
0·065	0·000	Sixpence	Great Britain	0·770	Round	Yes	No	Yes

Coins in Order of Thickness—*continued*

Thickness	Difference	Coin	Country	Diameter	Shape	Rim	Holes	Serration
in.	in.			in.				
0·065	0·000	20 cents	Straits Settlements	0·919	Round	Yes	No	Yes
0·065	0·000	2 annas (1926)	India	0·840	Square (radiused corners)	Yes	No	No
0·066	0·001	10 gramos	Spain	1·185	Round	Yes	No	No
0·067	0·001	10 groschen	Austria	0·870	Round	Yes	No	No
0·067	0·000	5 markkaa	Finland	0·902	Round	Yes	No	Yes
0·068	0·001	10 centimes	France	1·185	Round	—	—	—
0·069	0·001	10 cents (1915)	Belgium	0·867	Round	Yes	No	No
0·070	0·001	1 peso	Chile Republic	1·100	Round	Yes	No	No
0·071	0·001	100 reis	Brazil	0·830	Round	Yes	No	No
0·071	0·000	1 markka	Finland	0·943	Round	Yes	No	Yes
0·072	0·001	1 shilling	British West Africa	0·928	Round	Yes	No	Yes
0·073	0·001	10 lei	Rumania	0·909	Round	Yes	No	Yes
0·073	0·000	20 lei	Rumania	1·065	Round	Yes	No	Yes
0·074	0·001	1 penny	Great Britain	1·213	Round	Yes	No	No
0·074	0·000	10 centisimi	Italy	1·186	Round	Yes	No	No
0·074	0·000	Pennia	Finland	0·863	Round	Yes	No	No
0·074	0·000	200 reis	Brazil	0·994	Round	Yes	No	No
0·075	0·001	1 shilling	Great Britain	0·935	Round	Yes	No	Yes
0·076	0·002	8 annas	India	1·026	Round	Yes	No	No
0·076	0·000	1 rupee	India	1·206	Round	Yes	No	Yes
0·078	0·002	1 kroner	Denmark	0·989	Round	—	—	—
0·081	0·003	50 cents	Hong Kong	1·225	Round	Yes	No	Yes
0·084	0·003	1 000 reis	Brazil	1·029	Round	Yes	No	Yes
0·095	0·011	Half-crown	Great Britain	1·280	Round	Yes	No	Yes
0·095	0·000	Florin	Great Britain	1·130	Round	Yes	No	Yes

APPENDIX II

Gear Ratios*

Ratio of differential to rotor.

$$\text{Ratio} = \frac{\text{Revs. of sun}}{\text{Revs. of rotor}}$$

Revolutions of rotor per 1*d.*

$$\text{Revs. per kWh} = \frac{\text{Revs. per hour}}{\text{kWh per hour}}$$

$$= \frac{60S}{K}$$

$$\text{kWh per 1d.} = \frac{1}{P}$$

$$\text{Revs. of rotor per 1d.} = \frac{60S}{KP}$$

Revolutions of sun per 1*d.*

$$\text{Revs. of sun per 1d.} = \frac{A}{360}$$

$$\text{Ratio} = \frac{KPA}{S \times 60 \times 360}$$

$$= \frac{APK}{21\,600S}$$

Ratio of train (*smallest dial*) *to rotor.*

$$\text{Ratio} = \frac{\text{Revs. of smallest dial per kWh}}{\text{Revs. of rotor per kWh}}$$

Revolutions of rotor per kWh.

$$\text{Revs. per kWh} = \frac{60S}{K}$$

Revolutions of smallest dial per kWh.

$$\text{Revs. per kWh} = \frac{1}{10R}$$

$$\text{Ratio} = \frac{K}{S \times 60 \times 10R}$$

$$= \frac{K}{600SR}$$

[The discussion on this paper will be found on page 545.]

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* See list of symbols on page 528.

DISCUSSION BEFORE THE METER AND INSTRUMENT SECTION, 2ND APRIL, 1937

Mr. E. W. Hill: It is rather a dismaying thought that, owing to the fluidity of the design of prepayment meters at the present time, the information given in the paper is likely so soon to become out of date.

With regard to Appendix I, giving details of the coins of various countries, I can perhaps understand why the authors have thought fit to omit the British threepenny piece, but why they have felt that the British halfpenny is not entitled to inclusion I cannot understand; perhaps they will vouchsafe an explanation in their reply.

In Section (3.31) the authors comment on the drum or commutator switches and say " The cling between surfaces is considerable, since in general it is equal to the contact pressure." I do not know how they define " cling," but I imagine it could be defined as the amount of force to be applied to separate the surfaces. With sliding surfaces there is such a thing as the " coefficient of friction," which is the ratio between that cling and the contact pressure, and, except in the case of absolutely interlocking surfaces, the two are rarely equal to one another, the coefficient of friction generally being something less than unity.

As regards nomenclature, the authors are quite right in pointing out that in these days of two-part tariff slot-meters it is not necessarily correct to call a meter a prepayment meter, because it does not always prepay; there are frequent occasions when debts are run up and the customer post-pays. It would be better, therefore, to call such meters slot meters.

Section (3.33) refers to the way in which the motion from the fixed-charge collector unit is linked up with the motion derived from the registration in two-part tariff meters, and here I have a matter for criticism. It is quite true that as the motion comes out of the meter counting train it passes through a price-change unit and is then converted into money values, and after the motion which is derived from the fixed-charge unit has been delivered from that unit through its price-change mechanism that too is converted into money values; it is quite clear too that the two motions can be combined only when they thus have the same dimensions. Fig. 27(*c*) seems to indicate, however, that the connection between the two motions, namely that from the fixed-charge unit and that after the price-change of the meter unit, takes place between the coin mechanism and the differential. I submit that this is wrong. Fig. 28 seems to show correctly, however, that the connection occurs between the differential and the two price-changers, and not between the coin mechanism and the differential. I think there is a fundamental inconsistency there, and on reflection the authors may have to admit that Fig. 27 is wrong.

With regard to the use of some sort of rocking motion to avoid the necessity of change wheels in order to alter the fixed-charge assessment (page 534), the authors rightly say that " Charge has to be proportional to period between collections." But there is the difficulty that when one has to convert a rocking motion into an intermittent forward motion, then, unless the cycle of operations in connection with the rocking motion is small in comparison with the total collection period, an error may arise at the beginning. I do not understand what the authors mean when they say " The value of charge per coin has to be constant."

From the wording on page 534 it is difficult to grasp that in Fig. 30 the pinion riding on the top of the two wheels has an epicyclic motion and goes round the periphery of the two wheels; perhaps the authors could make this a little clearer.

I agree that the tariffs adopted have a very large influence on the design of prepayment meters, but there is something which has an almost equal influence, namely the question of fraud. There is no doubt that, if people were all sensible and honest, prepayment meters could be made with much greater simplicity, and therefore at much less cost, than is actually the case. The possibility of fraud is such a serious bugbear that it has prevented the adoption of slot meters in many countries abroad. Prepayment meters are becoming more and more complicated and therefore more and more expensive to make. If an inexpensive meter is required it is no use asking for greater and greater complication, because the more complicated the meter the more expensive it is certain to be, and the less reliable it is likely to be.

Mr. O. Howarth: The authors mention the influence of tariffs on design, and they say that there is in existence a very large variety of tariffs; but I do not think it is quite true to say that there is in existence a very large variety of tariffs for domestic consumers. While there is a very large variety of prices, they conform to relatively few and simple types of tariff.

In Section (3.22), referring to the flat rate with minimum charge, the authors state that so far as they are aware " there has been no demand for a prepayment meter to collect revenue under this tariff." The reason why there is no demand is that the manufacturers have never offered to supply one. Such a meter would presumably be more costly.

Turning to Section (3.26), the Hopkinson principle does not really apply to domestic supplies, for the simple reason that it does not take diversity into account. The fixed charge for domestic supply should not be proportional to the maximum demand; there are many other factors, and the maximum demand is a relatively minor one.

I do not quite understand what the authors mean when, in Section (3.27), they say " The feature of these tariffs is a change in price per unit depending upon the short-time rate of consumption."

In connection with optional coin meters, the development of which the authors mention, I should like to say that the penny is not very much use in an electricity meter, or, if it is now, it will not be in the future. If electricity is to be used in houses for heating, cooking, and washing, as well as for lighting, a penny is far too small a coin for the prepayment meter, because it runs out too quickly. Perhaps the new threepenny piece will help us, if the manufacturers can make a meter which will take it.

The two-part tariff meter with the variable fixed charge and the load-rate meter are, in my view, the prepayment meters which are of the greatest general use. Numbers of other types have been developed, but their use is likely to be very small and limited to certain areas where conditions are unusual. The ordinary flat-rate meter, charging so much per unit for lighting, limits the use of electricity to lighting, and does not fit in with the general idea of developing the use of electricity. Consumers do not always come to the supply undertaking when they buy an iron; if they have a flat-rate prepayment meter they have to insert coins so often that they cease to use the iron, and the impression is given that electricity is expensive. With a load-rate meter, however, automatically the iron is charged at a lower price. The load-rate meter seems to me to be the equivalent of the system of separate lighting and power rates, without the bugbear of having to have separate circuits, and the iron can be used from a lighting point. It seems likely, however, that the lower cost of the flat-rate prepayment meter will keep it in being for a considerable time.

The disadvantage of the load-rate meter is that hire and hire-purchase payments cannot readily be collected through the meter. On the undertaking with which I am connected we take the view that if we put a slot meter into a house we must collect all that the consumer may owe us through that meter; it is of no use sending him a bill in addition. Hire and hire-purchase payments can readily be collected by means of the two-part meter with a variable fixed-charge device. The disadvantage of this is arrears, but it is not a serious disadvantage; our experience is that it is only occasionally that we meet with difficulty. People who are using electricity for other purposes in addition to lighting do not go for very long without it, and in consequence they do not get seriously into debt on their fixed charge. Usually one shilling restores the supply, as they are only a few coppers in debt. Such a consumer generally has a wireless set, and in consequence he keeps the supply going, so that the arrears question is not very serious. In our area, the consumers with slot meters cannot afford to go away for a month's holiday; a week is as long as they are likely to take, so that they never become much in arrear. We limit the arrears to 4s., however, after which the meter ceases to debit any longer, and if the consumer wants to restore the supply he has to put in 5 shillings, 4 to pay off the debt and 1 for which he obtains value. If ordinary quarterly consumers get into debt they are cut off, with a certain amount of fuss and expense, and if they wish to be reconnected they have to pay off the debt and in addition pay a reconnection fee, which, while it is rather heavy, does not cover the cost of cutting off and reconnecting. We regard the 4s. as a reconnection fee in the case of the two-part tariff meter. There are other ways of overcoming the difficulty, e.g. there is a meter of this type so arranged that if the consumer gets into arrears he can secure an immediate supply by inserting a shilling, but the fixed charge goes up to double the rate until the arrears have been paid off.

The authors mention that one disadvantage of the slot meter is that it interrupts without warning. Undoubtedly this is a serious disadvantage, and it will become more serious as electricity is used more extensively. It is hard on the lady who leaves her dinner in the oven to come back and find that the prepayment meter has switched it off and it is not cooked. The provision of some warning is becoming increasingly important, and I hope that meter manufacturers will do something about it—without increasing the cost.

I do not agree with the authors' remark in Section (3.71) to the effect that with slot meters there is less accounting, because there is no bill. Very complicated systems and machines are used by an up-to-date supply undertaking in connection with prepayment consumers as well as others.

Mr. J. W. Carter: I think that the performance of prepayment meters is much better than might be surmised from the authors' statement on page 536 that the units supplied per coin vary and the average over a large number of coins is incorrect. The tendency for irregular switch tripping is well known, but can be tolerated if not too pronounced. Errors due to this cause invariably cancel, so that over a number of coins the units supplied are correct. Also the mechanical load imposed by the mechanism is negligible, otherwise it would be impossible to produce a satisfactory prepayment meter of the d.c. mercury motor type. Perhaps the authors have in mind some out-of-date patterns, or the two-part tariff meter for penny operation.

A much more serious defect is the uncritical nature of the coin test, in connection with which the authors remark that a washer or disc may happen to work the mechanism. This leaves the impression that such things find their way into prepayment meters by accident, whereas in practice the extensive use of substitutes for coins is a serious obstacle to the smooth working of a prepayment system. I would suggest also that, in general, designers have not gone far enough in providing easy facilities for changing the price per unit. A price change presents a problem to large users of prepayment meters. It is costly, and seriously upsets for many months at a time the whole routine of the people concerned. There is no reason why meters cannot be so designed that the alteration can be made by meter readers during their rounds and with little interference with their ordinary duties.

Mr. E. S. Ritter: There seem to be two broad classes of coin mechanism: first, there are those which are used by the public at large, and secondly those which are installed in some private house or on the premises of some firm where they are used by only a limited number of persons. Where the coin mechanism is in a public place and used by the public at large the checking of the coins and the rejection of unsuitable ones must be much more accurately done than where the mechanism is on private premises, and where the head of the household or the firm can be made responsible for any false coins found in the till. Each of the two classes above may be subdivided into those which deliver a commodity and those which deliver a service. Cigarettes obtained from a coin machine are commodities; and service is obtained when, for instance, a coin box is installed for telephones. As a general principle the public machines which deliver commodities must have safeguards which can often be dispensed with in machines delivering a service.

The public complain if good coins are rejected because they are worn, and, in order to cover this point, the tolerances on the machines have to be increased, thus adding to the risk of the acceptance of false coins. In the case of the stamp-selling machines used by the Post

Office, it has been found necessary to give a tolerance from 1·190 in. to 1·225 in., a difference of 35 mils in diameter, for pennies, and from 0·985 in. to 1·010 in., a difference of 25 mils, for halfpennies, to cover worn coinage.

I should like to ask whether the authors know of any satisfactory and successful resistance test, chemical test, rigidity test, and elasticity test, for coins which is in actual use. Are the coin testers shown in Figs. 3 to 6 of the paper patented?

British coinage when new is, I believe, correct as regards weight, but the Mint does not guarantee its thickness or diameter. This does not generally cause difficulty, because allowance has to be made for wear. On the other hand, weight tests are not very easily applied in practice, and, so far as milling tests are concerned, the milling wears rapidly and if small tolerances are used good coins will be rejected.

I have been asked whether the authors could add anything to Fig. 11 to show how many coins are included in any one year, and the variations in, say, diameter in that particular year. Three typical years might be shown. In the diameter very large discrepancies are shown. Are these due to mutilated coins? In Fig. 12, how has the thickness been measured? Have the authors any data for the thickness, measured between parallel plates, so as to allow for bent coins?

I should like to ask whether the authors have measured the threepence and sixpence of the Irish Free State, which are nickel coins, and whether they can confirm that the halfpenny, penny, shilling, two shillings, and half crown, of the Irish Free State are of the same weight as the British coins. How are the dimensions arrived at which are given for the various coins? Are they the maximum, the average, the dimensions of a single coin of each value selected at random, or the nominal new dimensions? Also, from what source have they been obtained? I ask this because the Mint has declined to give any dimensions for coins.

With regard to Section (2.42), the stamp machines shown in Figs. 16 and 17 differ slightly in certain details from the machines used by the Post Office. The main difference is the press button to open the coin-tester.*

Section (2.43) deals with the telephone coin box; the Post Office have two general types in use, the prepayment and the post-payment. The prepayment one has been described. It differs in a particular respect from the coin mechanisms which the authors generally have described in electricity meters in that it has to be able to refund the 2d. put in—the unit fee—on the pressing of a button. The post-payment coin box has been described elsewhere;† it operates as follows: The incoming coins actuate contacts which disconnect the ordinary transmitter momentarily and bring into circuit a transmitter, the sounds from which indicate to the operator the various coins put into the box.

Mr. E. H. Miller: If I were interested in the supply of electricity I should prefer, if possible, not to use meters at all; but, if this were impossible, I should begin with a quarterly meter, and if that did not cover all requirements I should have to adopt the prepayment type. If I then found I still could not cover all requirements I should have to use a fixed-charge collector, a load-rate meter, or one of the many alternatives now existing. I do not think, however, that electricity will ever be sold in the same way as water, i.e. without metering, simply because one's water-using capacity is very limited, whereas electricity is capable of being used in such a variety of ways. The only means whereby one could deal with the problem satisfactorily would be to use electricity in conjunction with a current-limiter, but we are all agreed that this practice is fundamentally wrong, because we wish to encourage the use of electricity in every possible way and not to limit its use.

It is not difficult for a man of average intelligence to make himself a piece of metal which has the same diameter, weight, and characteristics, as a coin of the realm. It is not very serious if these are used in house meters, because it is generally possible to get the consumer to exchange these " tokens " for proper coin of the realm, but of course if they are used in a telephone box or stamp machine they cannot be exchanged. I would therefore plead that callipering, hole-finding, and weighing devices be applied only to machines used by the general public, and that these devices be omitted from house-service meters, thus keeping the price within reason.

Mr. H. E. Angold: I sometimes think that we are being drawn into designing elaborate apparatus to collect a definite amount from the consumer, when all that is really needed is a collecting box. If one has an automatic collecting-box one finds from the bill what is due (the bill being completed after the meter has been read), helps oneself to the money in the collecting box, and gives the change back to the consumer. This seems to be a halfway method between the American system of having no prepayment meters and our way, which is to try to collect the exact amount. The method I have suggested could make use of the ordinary flat-rate meter, which is easily changed, and one could alter the price according to the requirements.

Consumers sometimes insert tin discs and other foreign matter, and I therefore think it would be a good thing if the collector could remove the front of the coin action without breaking the seal (once the seal has been broken it is necessary to bring the meter in and have it re-checked and re-certified). It would be a great advantage to be able to take out the coin action from the front of the meter and clear any obstruction away.

As regards the optional-coin meter, where there are separate slots for the various coins, I would point out that the slot can be so arranged that coins of smaller diameter cannot enter. An obstruction can be fitted which is removed only when a coin of the right diameter is inserted.

Mr. L. B. S. Golds: I should like to draw the attention of the authors to other factors than those mentioned in the paper that may govern the use of prepayment meters in overseas countries. There is, for example, the large amount of paper money in circulation. This is particularly the case in the Far East, where silver coins have been largely replaced by paper money. There are also coins of the same size but of lower value, due to repeated debasement of the coinage. On the other hand, in this country there is a greater necessity for prepayment meters owing to the payment of wages weekly and the presentation of accounts monthly or quarterly. I should mention that there is a tendency in other countries for all labour to be paid monthly, and accounts to be rendered monthly, with the result that the need for the prepayment meter is less and, incidentally, the cost of supply to the small consumer is reduced.

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* For further information on this subject see J. H. Combridge: *Post Office Electrical Engineers' Journal*, 1937, vol. 30, p. 18.

† W. A. Collett: *ibid.*, 1936, vol. 29, p. 178.

With reference to the demand for a small meter, this is not easily understandable, seeing that prepayment meters for other commodities are considerably larger in size than electricity prepayment meters. I think it would have been preferable if the demand had been for a more reliable and accessible meter; for as long as the meter is not unduly large or heavy there seems to be no gain in endeavouring to reduce its size to a point where the reliability, robustness, and accessibility of parts, are sacrificed.

When dealing with meters for special tariffs, the authors mention a step-rate meter whereby a high charge is made for so many units and the remainder are charged at a lower price. Under this system it is possible that the fixed charge may not be collected, and up to the present the system has not found favour generally.

Mr. A. J. Pitt: It has often occurred to me that the acceptance or rejection of a coin should take place outside the meter. If a coin is jammed in the meter, it usually means a service call and the meter has to be opened, involving some expense. I have in mind the pin-table machines where the coin is put into a tray and if that coin is of the wrong denomination, or is bent, it will not go into the machine.

In most prepayment meters the coin merely acts as a coupler between the handle and the switch. Certain precautions are taken with regard to the diameters of coins, but the tolerances are rather large, and the meter can be worked with something which does not at all resemble the shape of the coin; it may even be square, and I have known many meters which will work on a cardboard " coin " cut hexagonally, though these meters incorporate so-called coin selectors. If the diameter of whatever is used is the same as that of the coin the meter will work, irrespective of the shape of the object inserted.

The question of the design of prepayment meters has been looked at entirely from a drawing-office point of view; the point of view of the user does not seem to have been considered. There are many cases where it is necessary to dismantle a large portion of the meter to get access to the mechanism, and expense is incurred in removing the meter to remedy a trivial fault. Meter designers should take account of this factor, and should remember that the vital parts of a prepayment meter ought to be easily accessible.

It is not quite true to say that the majority of consumers using two-part tariff meters are poor; there are many instances of people in fairly comfortable circumstances who use the two-part tariff meter. I have met cases where the fixed and hire charges are 10s. a week, and yet many meters can only collect up to 4s. a week.

Mr. S. Hunt: With regard to coin measurements and the amount of work entailed on the part of the meter manufacturers in arranging their coin mechanisms so that they will reject coins of other than the right thickness or diameter, I do feel that too much importance has been given to this subject, since an electricity prepayment meter is different from the mechanisms needed by the Post Office. In their case, as well as in the case of cigarette and other automatic devices, the person inserting a wrong coin cannot be found if wanted; but where a consumer inserts a foreign or other coin, either by accident or by design, he can invariably be asked to make good such coins found in the coin box when the collector calls. Some years ago, a leading meter manufacturer produced a very simple hotel-type prepayment device, and supplied with it a number of brass discs which were used as tokens and could be purchased from the hotel booking-clerk, the price varying with the type of room occupied.

I am rather pleased to see that the authors mention the Mordey–Fricker prepayment meter. To my knowledge, this was the only prepayment meter made which gave a visual warning when the coin's worth was about to become exhausted. The nature of the meter was such that it could not but give this warning, so that no extra cost was entailed, such as would be if the present type of prepayment meter had to do the same.

Coming to two-part or rental meters, I would like to know of some simple method of checking the various settings which meters of this type can be set to collect. Such checking must occupy a very large amount of time in the test room, when dealing with quantities of meters of this type.

I have been very interested in the coins found in a batch of optional-coin meters installed in a block of workmen's dwellings. From several periodic collections it was found that 86 per cent of the coins inserted were pennies. In view of this information I am wondering whether the extra cost, and intricate mechanism involved, is really worth while, seeing that these meters may only result in a slight increase in consumption.

In conclusion, I look forward to the time when all prepayment consumers will be able to have a flat rate per unit for all purposes, so that only a simple type of prepayment meter will be required; as the maintenance and repair costs of the wonderful contrivances which are being called for from the meter manufacturers from time to time, and which of necessity contain a vast number of wheels, springs, levers, etc., will mount up to very high levels.

Messrs. J. Prince and **M. Whitehead** (*in reply*): The main point that emerges from the discussion is a plea for simplicity in prepayment meters because complicated mechanisms are troublesome and costly. Complication may arise because design has not become stabilized or because of too many special requirements. It appears to be generally agreed that tariffs have a large influence on design, but there is no general agreement regarding the direction in which development should take place.

It is stated in the paper under Section (3.8) (Conclusion) that " Despite the fact that the idea of coin mechanisms is comparatively old, very few general principles appear to have been laid down. It has been found possible to state the broad principles under which coin mechanisms of whatever type operate." We, therefore, do not share Mr. Hill's pessimism regarding the rapid dating of the information, since we are of the opinion that the principles laid down will form a basis for further study.

Regarding the omission of the British halfpenny from Appendix 1, we would point out that the selection was arbitrary. The dimensions are given in Figs. 7 and 8 of the paper.

We must thank Mr. Hill for pointing out an error in the note on commutator switches (Section 3.31). The cling is not equal to the contact pressure but proportional to it; nevertheless we believe the cling in this type of switch to be considerable.

Regarding the reference to Fig. 27(*c*), it was not our intention to imply that the connection between the two motions, namely that from the fixed-charge unit and that after the price-change unit of the meter, takes place only between C and D. Fig. 27 was designed to show that the connection of the two motions may take place at any point between C and the price-change unit, irrespective of the position of the differential. The price change may occur on either side of the differential, and in fact is shown in those two positions in Fig. 28.

Mr. Hill agrees that in charge-change mechanisms the time for one cycle should be small compared with the time between collections. The time for one cycle should also be small compared with the time equivalent to one coin. If a consumer is not using current or is using only a small constant amount and therefore in effect merely keeping pace with the fixed charge, large discrepancies in time between one coin and the next would result in suspicion and complaints, in the same way that suspicion arises when large variations in units per coin arise. This is what is meant when it is stated that the value of charge per coin has to be constant.

Referring to Fig. 30, if we assume that both sun wheels have the same number of teeth and are in mesh with the one pinion, then if one sun wheel is held stationary and the planet system rotated completely round the sun wheel there will be no movement of the free sun wheel. If, however, the latter has one tooth less, under the same actuation conditions instead of it remaining stationary it will move forward one tooth.

With regard to the point raised by Mr. Howarth, it is perhaps a matter of opinion what constitutes a large variety of tariffs. The tariffs vary not only in type but also between similar types in the methods of assessment. For example, taking the case of the two-part tariff, whilst this is only one tariff there are at least eight different ways of assessment.

Referring to the point of the Hopkinson principle not applying to domestic tariffs (Section 3.26), we would point out that in this section the principal tariffs were reviewed with reference to their possible effect on meter design.

The phrase " short-time rate of consumption " is intended to imply average power over an extremely short time to distinguish from average power over a long period of time, e.g. a month. The review of the advantages and disadvantages of the load rate meter, together with Mr. Howarth's experience in the system with which he is connected, is extremely valuable.

We are pleased to note his agreement with the statement that a serious disadvantage of the slot electricity meter is that it interrupts the supply without warning, but we fail to appreciate how a warning device could overcome the difficulty in the case he cites.

We agree with Mr. Carter's remarks that the irregular switch tripping can be tolerated if not too pronounced. We wish we could agree with his general statement that mechanical load imposed by the mechanism is negligible. Whilst we realize that there are now meters arranged for certain coins and for certain prices per unit where the effect is extremely small, there are a great many other coins and prices where the load imposed is far from negligible, even in meters of modern type.

We find ourselves in complete agreement with Mr. Ritter's remarks regarding machines in public and private places, and note with interest the permissible tolerances on the penny and halfpenny coins when used in stamp-selling machines.

We do not know of any resistance or chemical test which is in practical use: these methods have been suggested and have been the subject of experiment. Regarding rigidity tests, a method is shown in the paper in Fig. 3(*a*) (illustration primarily intended to show tests for diameter and thickness) and in Fig. 25 (example of modern meter). Here the coin must form a transmission piece between two rotary members, a condition which is only fulfilled when the coin is rigid. The coin-test methods described in Figs. 3 to 6 are covered by patents, but the actual illustrations in the paper are not intended to represent any particular patent drawing or manufacture.

Table A

Coin	Weight (grains)	
	Irish Free State	British
¼d.	44	43
½d.	88	85
1d.	147	142
3d.	51	21
6d.	71	43
1s.	87	85
2s.	188	174
2s. 6d.	217	218

The information regarding the number of coins included in any one year (Fig. 11) is detailed in Fig. 10. Regarding variations in dimension in any one year, we are able to give these in Figs. A, B, and C, which show diameter, thickness, and weight, against frequency for the year 1921 of Fig. 11. Discrepancies in the maximum curve of Fig. 11 are due to mutilated coins, but discrepancies in the minimum curve are not due to mutilation and therefore must be put down to wear. The diameters of the Irish Free State 3d. and 6d. coins are 0·699 in. and 0·825 in. respectively, and the thickness is in each case 0·072 in. A comparison between the weights of the Irish Free State and British coins is given in Table A.

Coin thickness as shown in Fig. 12 was obtained by laying the coin down on a flat plate and exploring the upper surface with the feeler of a gauge: the maximum reading was noted and this automatically gave the maximum figure, even in the case of a bent coin. The dimensions obtained for the various coins are in some cases obtained from single coins, but where more than one coin was available the coin showing the least wear was selected.

We must thank Mr. Ritter for his further information on Post Office coin mechanisms.

Mr. Miller's point of view is a natural one. He would use prepayment meters only as a last resort if he were interested in electricity supply, and then it would be preferable for them to be of a simple type, free of all coin-gauging devices. The prepayment meter, however, appears to be fully justified on economic grounds: in some cases it is the best means of revenue collection and in others it is the deciding factor in favour of a supply.

Mr. Angold, too, thinks that prepayment devices may be too elaborate, and suggested a collecting box in conjunction with a quarterly meter. The collecting box may be a simple money box, with no relation to time or to the supply, or it may be what is known as a fixed-charge collector as mentioned in Sections (3.25) and (**3.33.**) Both these systems are of course in use, but a possible disadvantage of the simple money box is that at the end of the quarter it may not contain any money.

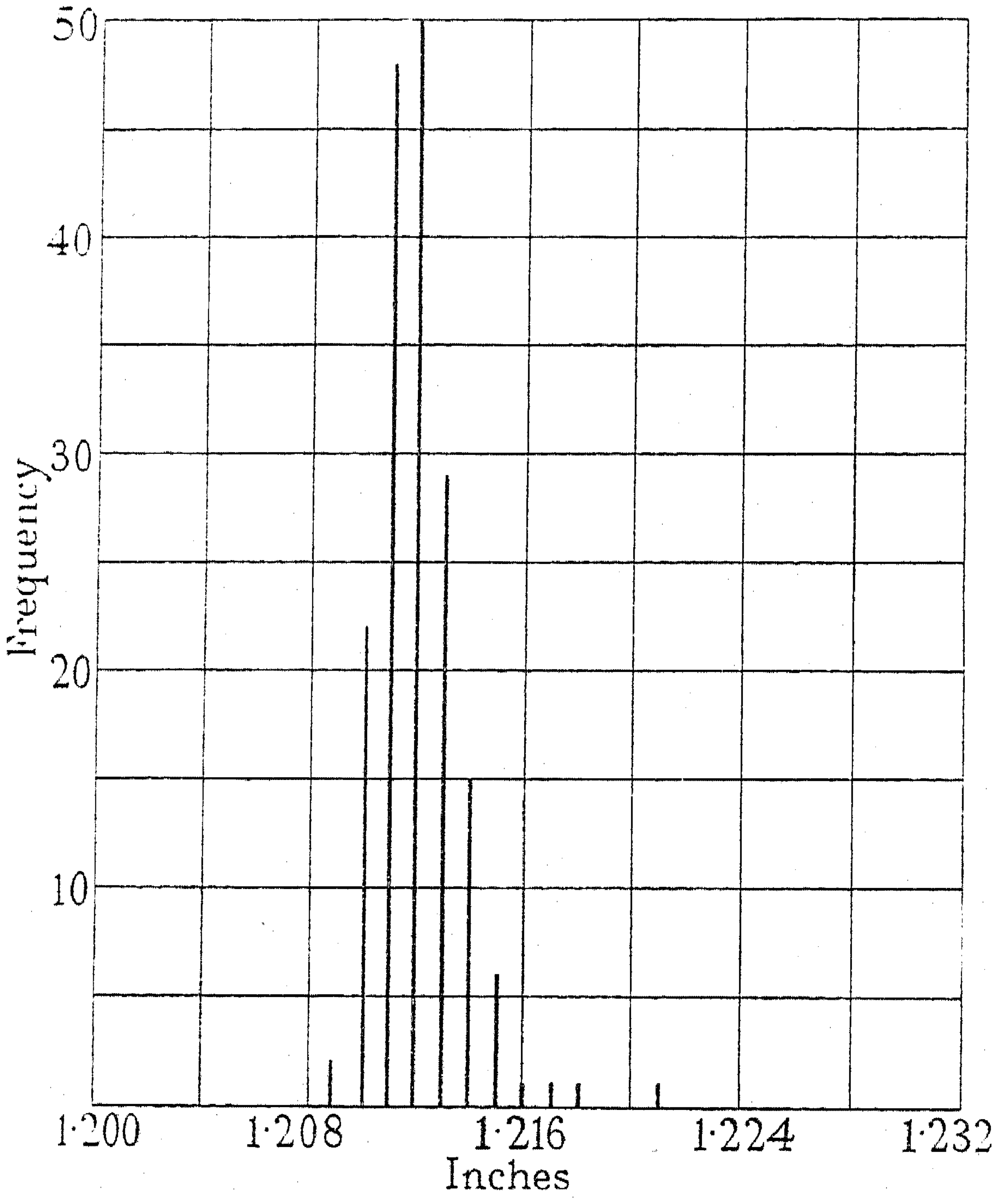

Fig. A

Average diameter = 1·212 in.

If it is true that once the meter seal has been broken, it is necessary to bring the meter in to be re-checked and re-certified, then we agree that it would be advantageous to have separate and independent access to the measuring portion and the prepayment mechanism portion of the meter.

We note the additional reasons for the non-use of prepayment meters, particularly in the Far East, advanced by Mr. Golds, but we are still of the opinion that the major objection is the legal requirements relating to prosecution. We agree with the remarks that there is little to be gained by reducing the size of meters at the sacrifice of performance, but we would point out that there is much to be gained by reducing the size and maintaining an equal performance.

When Mr. Pitt refers to acceptance or rejection of coins taking place outside the meter, we take it that he means outside the whole case which contains both meter and mechanism, because there are in existence several examples where the coin mechanism is separate from the meter proper. He instances the " pin table " mechanism as an example where the coin if of wrong denomination will not enter the machine, but we submit that this is true only for wrong denominations of greater diameter. It is agreed that the precautions taken to prevent the insertion of a wrong coin are not so great in prepayment

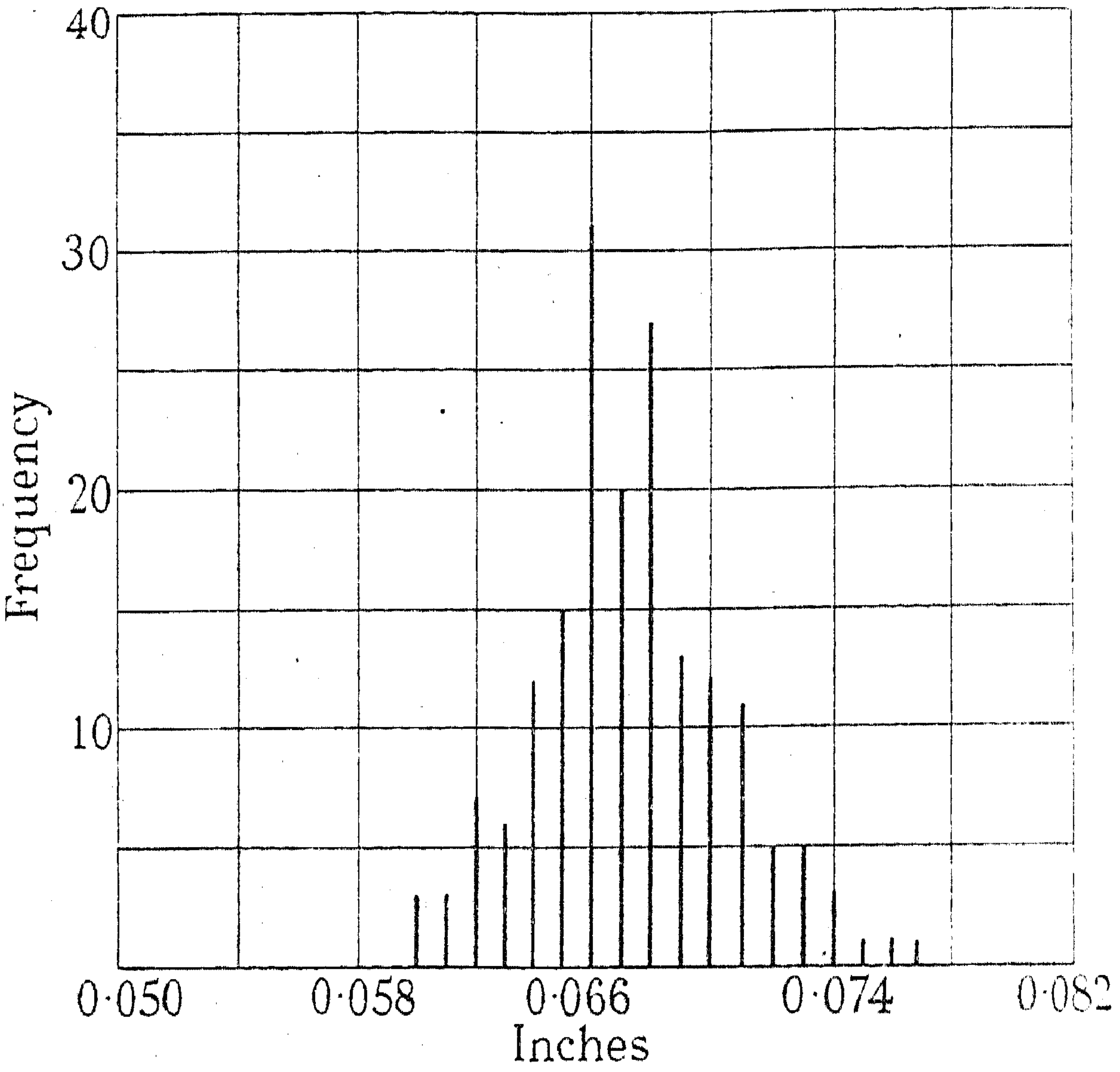

Fig. B

Average thickness = 0·067 in.

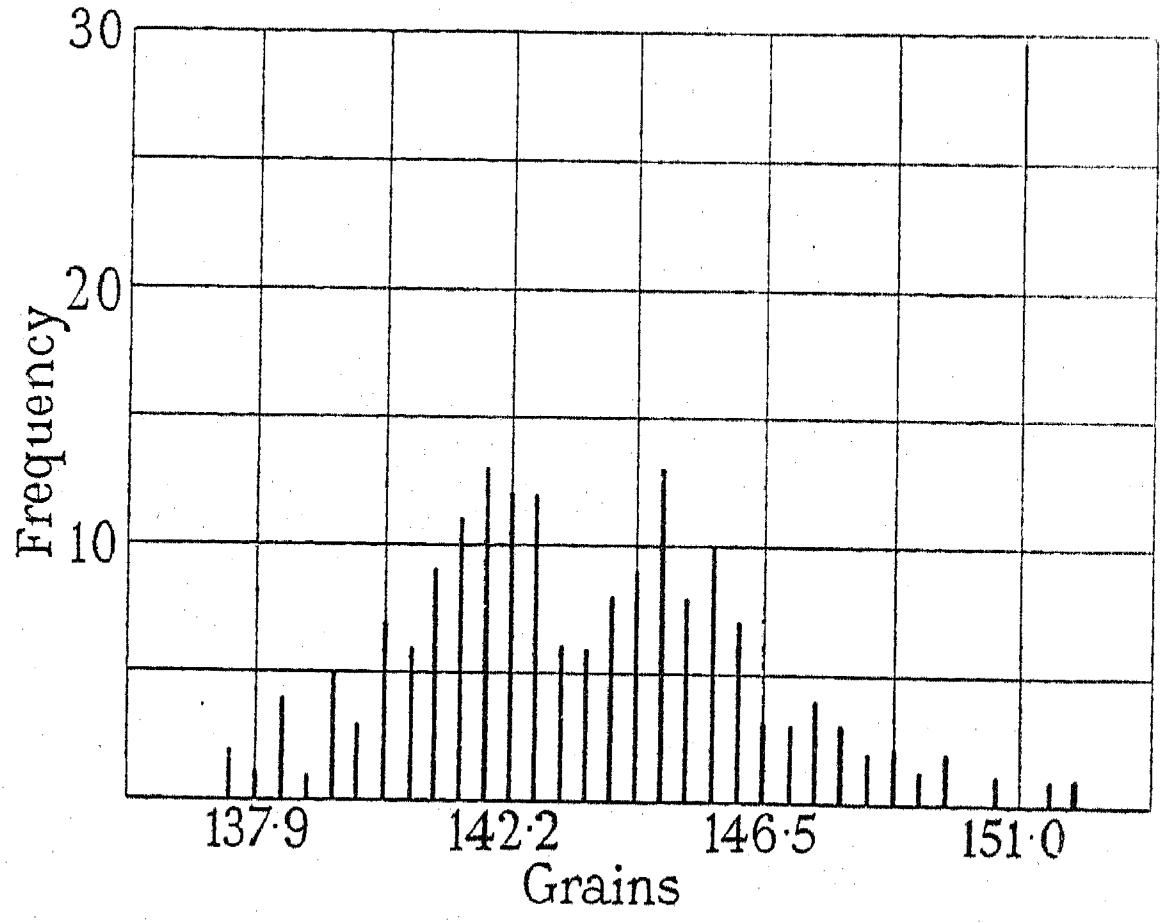

Fig. C

Average weight = 143·5 grains.

meters as in public vending machines, and it is generally agreed, as is evidenced by several speakers with whom we agree, that these precautions are not so necessary.

Regarding the design of prepayment meters and in fact the design of any commercial device, Mr. Pitt is naturally aware that price is considered in addition to performance, accessibility, dimension, and customer's particular requirements, and that once the preliminary design has been established it passes through many stages in addition to the drawing office. We are certain that prepayment meters better than any now on the market can be produced, but we feel that the price would be too high to be in the best interests of electrical development. We note the statement regarding the use of two-part tariff prepayment when fixed and hire charges up to 10s. per week are collected, and if a reasonable demand for this meter exists we know of no reason why it would not be met.

Mr. Hunt's comments regarding the elaborate testing of coins in prepayment meters and public vending machines have been mentioned by previous speakers and we feel that they represent a fair view of the position.

Regarding the testing of two-part tariff or rental meters, we know of no method that is both simple and comprehensive. The chief methods are as follows:—

(1) Check fixed-charge unit under conditions similar to the working conditions, i.e. assembled in meter with the synchronous motor running down the tripping gear, the time of operation being checked against clock mechanism.

(2) Similar to the above, but the synchronous motor is energized with a higher-frequency supply.

(3) Use of a special gear unit fitted to the mechanism to speed up the gear drive from the motor.

Mr. Hunt states that he has found in one case that 86 % of the coins inserted in optional-coin meters were pennies and therefore concludes that some doubt exists as to the desirability of the optional-coin meter. We ourselves are in some doubt regarding the interpretation of this information, because, assuming a two-coin meter, the corresponding values of pennies and shillings are 7s. 2d. and 14s. respectively, and the money values are only equal when the percentage of penny coins is between 92 and 93.

DISCUSSION ON

"THE EFFICIENT RATING AND DISPOSITION OF SUPPLY APPARATUS ON HIGH-VOLTAGE URBAN SYSTEMS"*

FURTHER COMMUNICATION TO THE DISCUSSION

Mr. S. R. Mellonie (*communicated*): There appears to be an arithmetical error in Table 3 (page 239) where the value given for the impedance in the first line should read "0·081" in place of "0·1125." The figure should, in fact, be the same as that in the third line where the ratio of the initial MVA to the reduced MVA is the same. It may easily be shown that, for a given system, if this ratio is constant then the ohms per phase are inversely proportional to the lower value of MVA.

The following expressions cover certain of the quantities in Table 3. These have been found very useful in planning high-voltage systems, and may be of interest to others.

If at any point on the system the fault kVA is F and it is desired to make an extension to a point where the fault kVA should not exceed P kVA, then, if the interconnector has an impedance of X %, the limiting rating R of the reactor, transformer, or interconnector, is given in kVA by

$$R = \frac{XFP}{100(F-P)} \quad . \quad . \quad . \quad . \quad (1)$$

Now if Z is in ohms per phase, I the current, and E the line voltage, we have

$$IZ = \frac{X}{100} \cdot \frac{E}{\sqrt{3}} \quad \text{and} \quad R = \sqrt{3}EI \times 10^{-3}$$

Substituting these values in (1) and transposing, we get

$$Z = \frac{E^2(F-P)}{1\,000FP} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

It is interesting to note that I does not occur in this expression, although, of course, the value of the current determines to a large extent the cost.

Further, let $\frac{F}{P} = n$, then

$$\frac{F-P}{FP} = \frac{1}{P}\left(\frac{n-1}{n}\right)$$

Substituting this in (2) we obtain

$$Z = \frac{E^2}{P}\left(\frac{n-1}{n}\right)10^{-3} \quad . \quad . \quad . \quad . \quad (3)$$

From this it will be seen that, for a given system and a given value of n, the ohms per phase are inversely proportional to the lower value of the MVA, as stated above.

As a further check on the figures in Table 3 it may be observed that as the ratio 500/250 is the same as 1 500/750, and 250 is one-third of 750, the number of ohms per phase in the first line should be one-third that quoted for the 500/250 case, i.e. 0·242/3 = 0·081.

Mr. J. Eccles (*in reply*): I thank Mr. Mellonie for pointing out the arithmetical slip in Table 3. The correct value of the impedance in the first line should be 0·081 ohm per phase and the percentage regulation at unity and 0·8 power factor should be 0·111 and 1·61 respectively. The reactance theorem as stated by Mr. Mellonie is very useful in the quick estimation of the reactance required for specified reductions in power concentration, and hence deserves to be more widely known.

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* Paper by Mr. J. Eccles (see page 229).

DIRECTIONS FOR THE STUDY OF HARD COMPOSITE DIELECTRICS (MOULDINGS, SHEET, AND THE LIKE)*

[REPORT (REF. B/S3†) OF THE BRITISH ELECTRICAL AND ALLIED INDUSTRIES RESEARCH ASSOCIATION]

(*Paper received* 10*th February*, 1937.)

SUMMARY

As a result of the experience gained since the issue of Refs. B/S1 and B/S2 it has been found desirable to modify several of the tests hitherto applied to hard composite dielectrics (mouldings and the like) and to introduce a series of "temperature grades" which, although purely arbitrary, are closely related to the different classes of composites in general use.

The tests described in this report are not intended as acceptance tests in the purchase of such materials, but it is anticipated that the British Standards Institution will issue a series of purchasing specifications,‡ based largely upon these recommendations, which will define appropriate limits to the specified electrical and mechanical properties for the class of materials covered by this report.

The Director of the E.R.A. will welcome comments and suggestions from those who may have occasion to make use of this report.

CONTENTS

(1) Introduction.
(2) Temperature Grading.
(3) Conditioning.
(4) Volume Resistivity.
(5) Surface Resistivity.
(6) Electric Strength.
(7) Power Factor and Permittivity.
(8) Tensile Strength.
(9) Cross-Breaking Strength.
(10) Resistance to Crushing.
(11) Impact Strength.
(12) Plastic Yield.
(13) Accelerated Ageing.
(14) Density.
(15) Water Absorption.
(16) Machining Properties.
Bibliography.
Appendix I. Notes on Conditioning Chambers and their Equipment.
Appendix II. Tables.

(1) INTRODUCTION

For the purpose of this report the term "hard composite insulating material" includes all non-laminated materials§ produced by mixing together suitable constituents—generally a binder and a filler—which pass through a plastic state in being formed into sheets or pressed into moulds, hard vulcanized rubber, vulcanized bitumens, hot pressings, and cold mouldings.

Special non-ignitable composites produced primarily for resistance to heat (e.g. asbestos board) are excluded from the present report because they are dealt with elsewhere.† This exclusion, however, does not relate to high-grade dielectrics that are, incidentally, heat-resistant.

(2) TEMPERATURE GRADING

The temperature grade of hard composite dielectrics is determined in the first instance by means of the plastic yield test. If a material purports to have a specified temperature grade it must fulfil at that temperature the requirements of appropriate British Standard Specifications, with respect to certain other physical properties.

The following tentative classification is proposed as having as close a relation as possible to the various types of hard composite dielectrics of commerce:—

Temperature Grade 0;	plastic yield above 300° C.
Temperature Grade I;	plastic yield above 200° C.
Temperature Grade II;	plastic yield above 140° C.
Temperature Grade III;	plastic yield above 100° C.
Temperature Grade IV;	plastic yield above 70° C.
Temperature Grade V;	plastic yield above 55° C.
Temperature Grade VI;	plastic yield not specified.

Grade 0 covers all types of heat-resisting composites, including those described as non-ignitable and self-extinguishing and further classified as such in Ref. A/S25.‡

Grade I includes cement-type composites of a slightly lower temperature grade than Grade 0, and also certain synthetic resin mouldings.

Grades II and III cover the vast majority of the more usual types of synthetic-resin composites, Grade III having a definitely low deforming temperature for this class of material.

Grades IV and V are principally (though not necessarily) hard rubber; those in Grade IV being loaded, while those in Grade V are pure rubber-sulphur compositions of high electric strength and low dielectric loss.

Grade VI is for composites of a definitely low yield-point which may be expected to have a limited industrial value when not mechanically stressed.

It is important to note that the relation between temperature and yield (deflection) is complex and cannot be dissociated from two other related variables, viz. stress and time. Consequently, the temperatures set for grading should not be applied to design problems in which the stress conditions differ widely from those of the test. Plastic yield phenomena have been investigated at some length by the Association and are dealt with in detail by a separate report.*

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* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of The Institution not later than one month after publication of the paper to which they relate.

† Superseding Refs. B/S1 and B/S2. [See Bibliography, (1) and (2)].

‡ See Bibliography, (3).

§ *Ibid.*, (4).

† See Bibliography, (5).

‡ *Ibid.*, (6).

(3) CONDITIONING

The electrical and mechanical properties of dielectrics are influenced to a considerable extent by their moisture content and temperature. It is thus necessary to have complete control over these two factors (or at least a knowledge of them) when making observations such as are indicated in the following pages. When a specimen is moved to an atmosphere of different relative humidity, or different temperature, a change of moisture content will take place. In general this change will be relatively rapid at first and will continue at a decreasing rate until equilibrium is attained. In some cases this will take but a few hours, but in others it may take many weeks. Obviously it is impracticable to "condition" a specimen for weeks, consequently a compromise has to be adopted (except where the highest possible accuracy is desired) so as to bring the error, due to this cause, within the permissible tolerances. For all tests not calling for special conditions (which must be clearly defined) the specimen should be "normalized" in an atmosphere of 75 % relative humidity at 20° C. ± 5 deg. C. for not less than 48 hours, and should be tested (if possible) in that atmosphere, or in any case within 3 minutes of removal.

Apparatus that has been found suitable for the production and maintenance of specified ambient conditions is described in Appendix I.

If it is deemed advisable, each specimen may be cleaned before conditioning by wiping carefully with a soft rag (one that does not lint easily) either dry or moistened with petroleum spirit.

(4) VOLUME RESISTIVITY

(a) Specimen.

The resistivity of hard composite dielectrics shall be tested on sheet specimens of not less than 4 in. diameter (or 4 in. square). For this purpose the specimen described in Clause 6(*a*) (i) may be used.

(b) Conditioning.

In the absence of any instructions to the contrary the specimen shall be "normalized" in accordance with Clause (3).

The following standard conditions are also recognized and should be adopted, wherever possible, in cases where normal conditions are not appropriate:—

Very dry Dry Damp Tropical Chemically treated	For an interpretation of these terms see Appendix II.

(c) Method.

The test consists in applying a known voltage ($E = 500$ volts) across the specimen when set up with electrodes and guard ring as shown in Fig. 1, measuring the resulting current I with a sensitive galvanometer and calculating the resistance R from the expression $R = E/I$. The resistivity shall be expressed in megohms for a centimetre cube after 1, 2, and 10 minutes' electrification respectively.

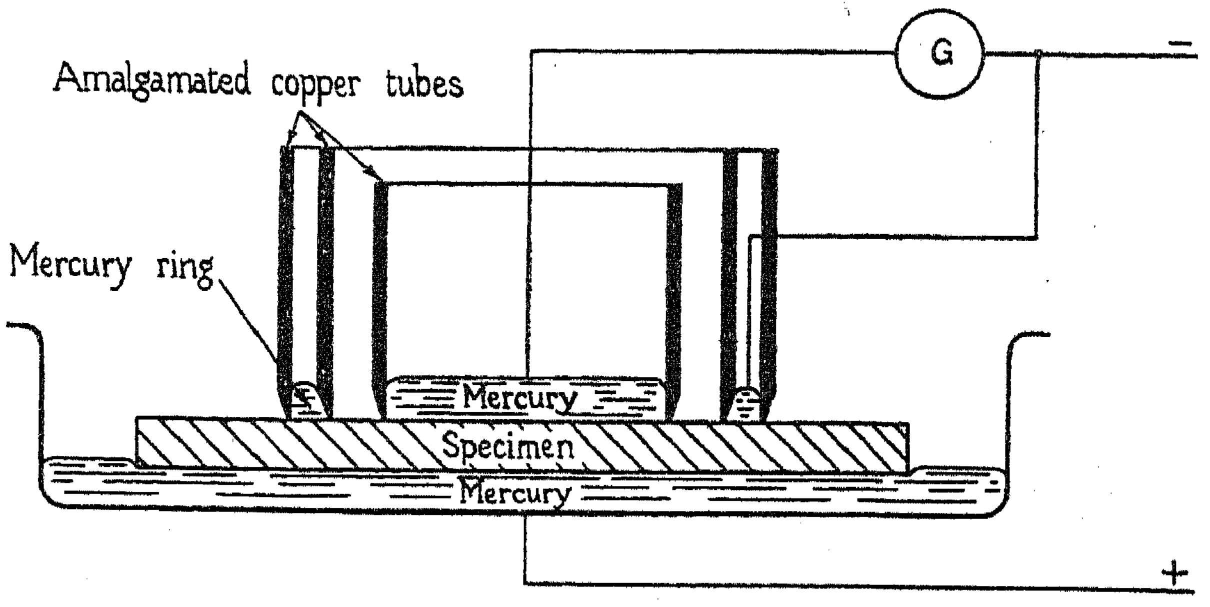

Fig 1.—Diagrammatic arrangement of apparatus for volume resistivity test.

The following apparatus is required:—

Galvanometer. Sensitive, reflecting type.
Shunts and keys appropriate to the above.
Mercury bath in which to float specimen.
Electrodes as shown in Fig. 2.

The use of graphite electrodes is permissible when it is not convenient to use mercury. Graphite* may be applied direct to the surface either as a powder (leiterit) or as a liquid† (aquadag), a stencil, as shown in Fig. 3, being used to ensure dimensional accuracy. In reporting results, the nature of the electrodes should always be specified.

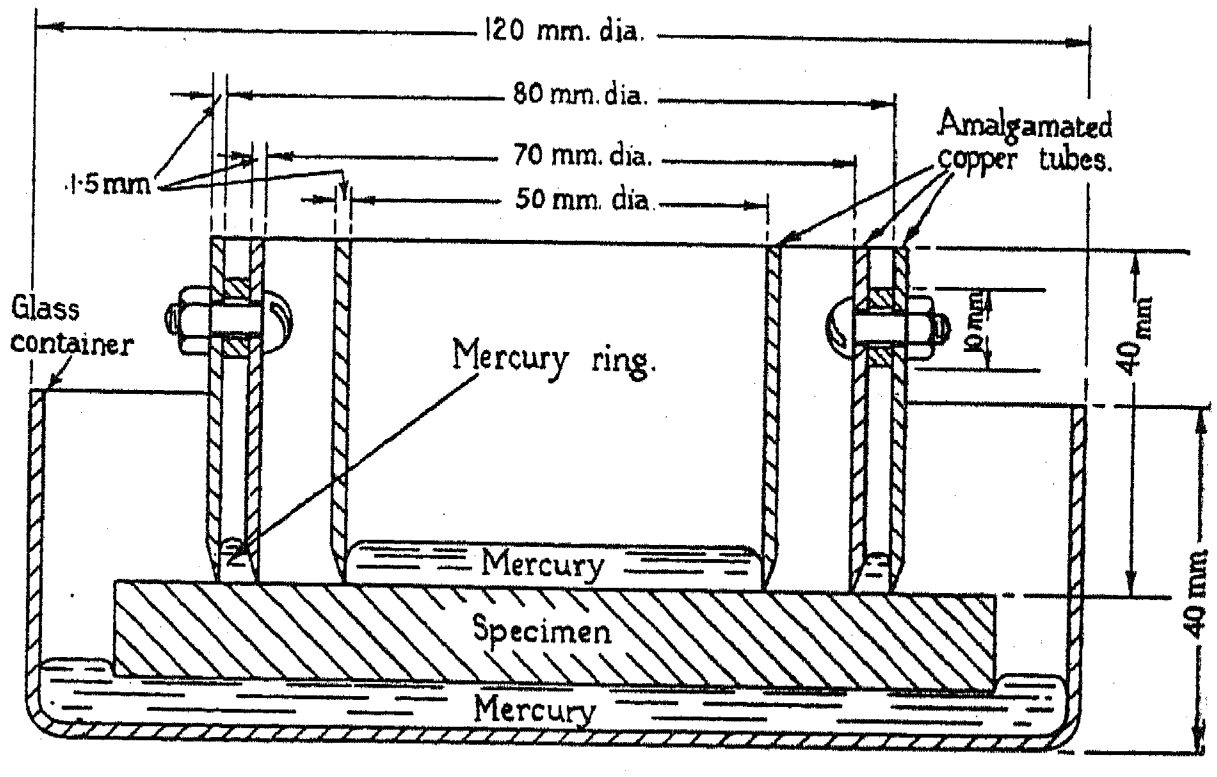

Fig. 2.—Form of apparatus for volume and surface resistivity tests. (U.S. Bureau of Standards.)

(d) Sensitivity.

The galvanometer determines the sensitivity of the method. A highly sensitive reflecting galvanometer will give a deflection of 1 mm. (at 1 m. distance) with a current of 10^{-10} amperes. A specimen having a resistance of 5×10^{12} ohms will pass this current when a p.d. of 500 volts is applied. Then, assuming the specimen is 3 mm. thick and 20 cm^2 in area under the upper electrode, the resistivity of the material will be about 3×10^{14} ohms per cm. cube (i.e. 3×10^8 megohms). This probably represents the operating limit of the method.*

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* See Bibliography, (7).

* See Bibliography, (8).

† Aquadag should not be used if the material is absorbent.

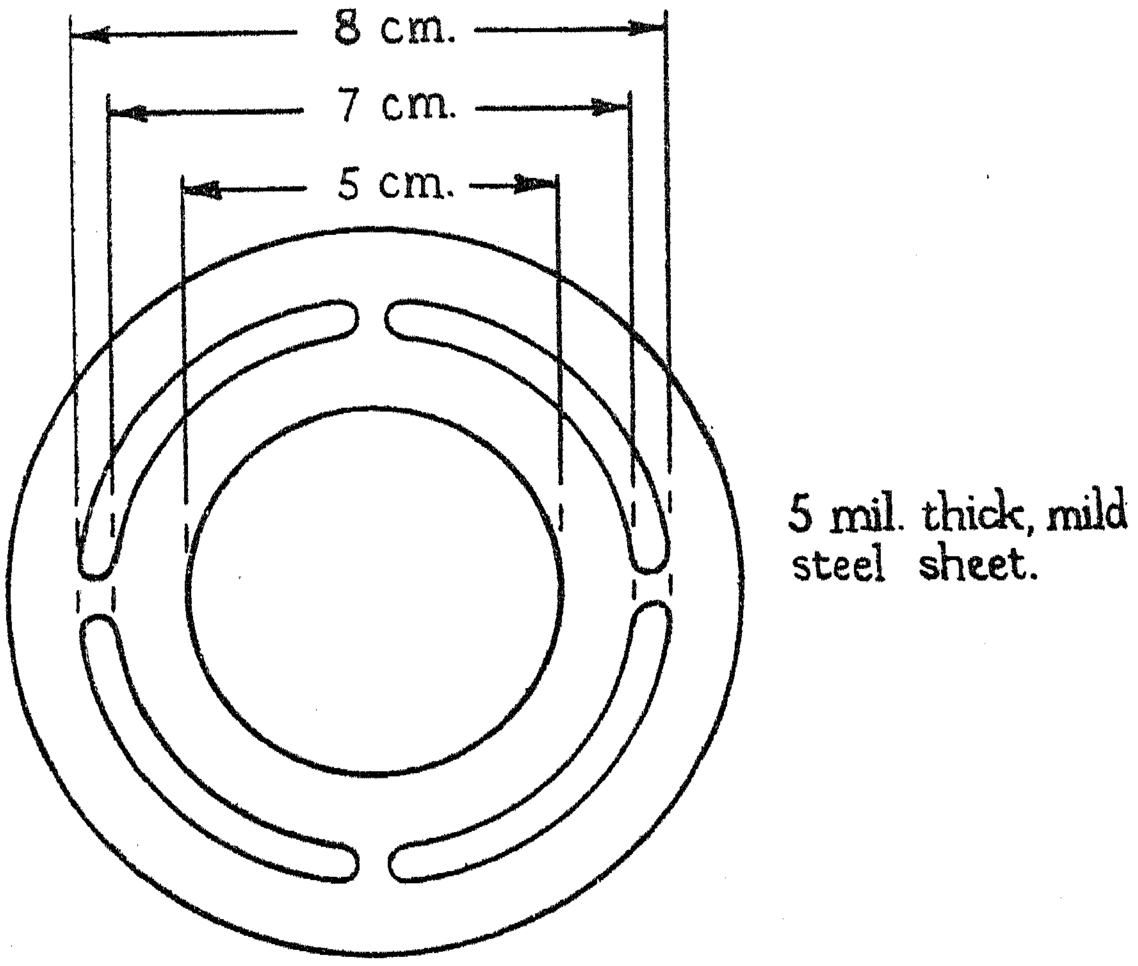

Fig. 3.—Stencil for graphite electrodes.

(5) SURFACE RESISTIVITY

For determining the surface resistivity the apparatus used is the same as in the test for volume resistivity, but the connections are modified as shown in Fig. 4. Recommendations regarding the size and condition of specimen are as given in the previous clause. With these connections the only current which passes through the galvanometer is that which flows over the surface of the material across the annular gap between the guard-ring and the inner electrode.†

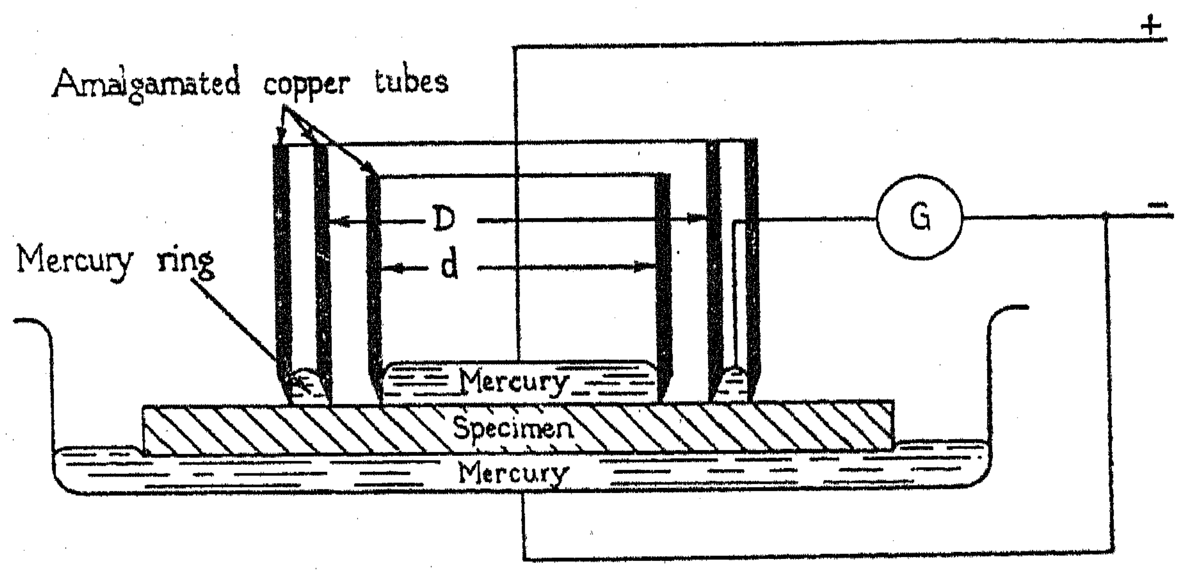

Fig. 4.—Diagrammatic arrangement of apparatus for surface resistivity test.

The surface resistance (S) of the specimen is found by dividing the voltage by the current as before.

The surface resistivity (s) is then given accurately by

$$s = \frac{2\pi S}{\log_e\left(\frac{r_2}{r_1}\right)} = \frac{2\pi S}{2{\cdot}3026 \log_{10}\left(\frac{r_2}{r_1}\right)}$$

where

r_2 = external radius of annular gap,
r_1 = internal radius of annular gap.

For all ordinary purposes, the following approximate formula suffices, provided that r_1 is much greater than $(r_2 - r_1)$

$$s = \frac{\pi S(r_2 + r_1)}{r_2 - r_1}$$

Since $r_2 - r_1 = 1$ cm., in the case of the electrodes specified above, it follows that for these electrodes

$$s = CS$$

where

C = mean circumference of the electrodes.

The surface resistivity expressed in megohms per cm. square is calculated after 1, 2, and 10 minutes' electrification respectively.

(6) ELECTRIC STRENGTH

The electric strength of solid insulating materials depends upon many factors, among which may be mentioned the following:—

The nature of the stress, e.g. continuous or alternating; high frequency or low frequency.
The duration of application of stress.
The rate at which the stress is augmented.
The nature and shape of the electrodes.
The temperature of the specimen.
The thickness of the specimen.
The " condition " of the specimen.
The nature of the ambient medium.

The Electrical Research Association has published a technical report* detailing the methods recommended for carrying out a thorough investigation of the influence of these factors upon the electric strength of solid dielectrics. This report should be consulted if any attempt is made to obtain complete information on the electric strength of a material. A further report,† giving details of routine tests, is in preparation.

The requirements of the present specification will, however, be met by the following details which are either based upon, or abstracted from, the above-mentioned reports.

Figures of electric strength obtained in this manner are for comparative purposes only and are not necessarily applicable to design purposes.

(a) Specimen.

(i) The specimen shall be machined or moulded to the form of a flat sheet or disc, preferably not less than 4 in. diameter and approximately $\frac{1}{8}$ in. thick.

(ii) In the case of high-grade dielectrics where the breakdown value is expected to exceed 1 200 volts per mil, and also in the case of low-quality materials when it is desired to examine the interior of sheet or mouldings, the specimen shall be machined or moulded as shown in Fig. 5. The recesses are to be truly spherical and must lie on a common axis. The wall thickness at the bottom of the recesses shall be 20 mils, a tolerance of ± 2 mils being allowed.

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* If it is desired to measure higher resistivities than this (e.g. as given by unloaded ebonites), recourse must be had to electrometer methods. A paper in which a suitable method is described is given in item (9) of the Bibliography.

† This assumption is not strictly correct since a certain amount of penetration through the body of the material takes place.

* See Bibliography, (10).

† *Ibid.*, (11).

(b) Electrodes.

(i) The electrodes recommended for sheet material, other than those required for (*a*)(ii) above, shall be as shown in Fig. 6.

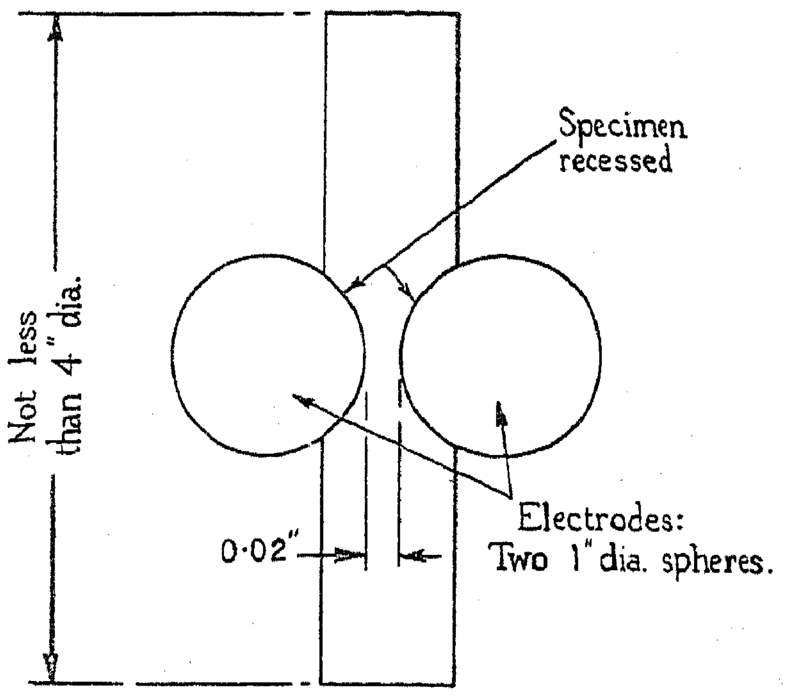

Fig. 5.—Electrodes for use with materials having an electric strength greater than 1 200 volts per mil, or for investigating the electric strength of the interior of any material.

The bottom electrode shall consist of a flat* disc of brass 3 in. diameter by 1 in. thick.

The top electrode shall be a solid cylinder of brass 1½ in. diameter by 1½ in. high, and shall be pressed into contact with the sample by a pressure of about 50 pounds.

The sharp edges shall be removed from the electrodes, but the radius at the edge must not exceed $\frac{1}{32}$ in.

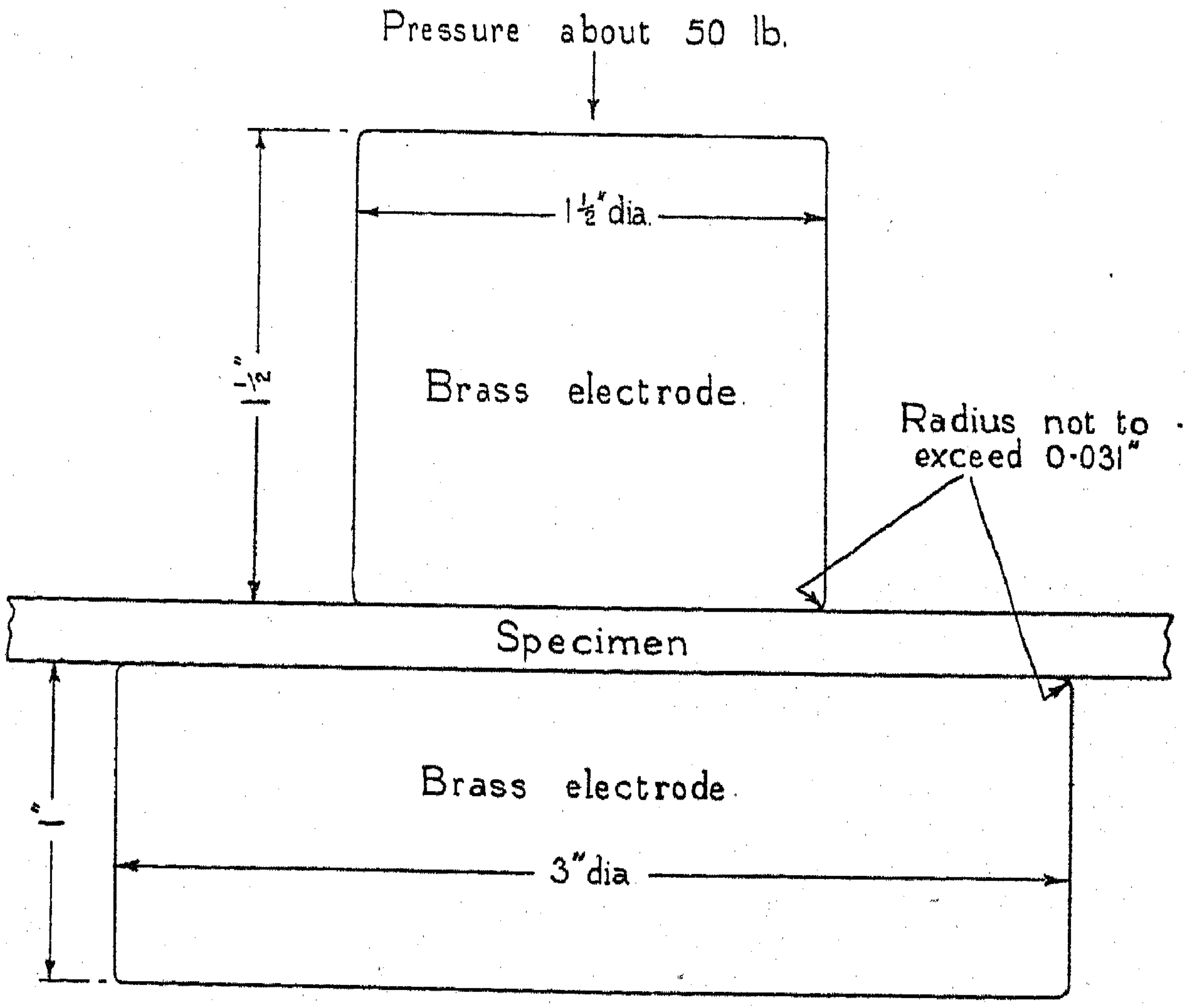

Fig. 6.—Electrodes for use with materials having an electric strength less than 1 200 volts per mil.

(ii) When it is necessary to employ recessed specimens [as defined in (*a*)(ii)], the electrodes shall consist of two 1-in. spheres of brass or any other suitable metal. It is essential that these spheres should bed down properly in the recesses. Good contact is imperative, especially at the centre.

(c) Power Supply and Test Equipment.

The testing transformer shall be of sufficient capacity to maintain on the sample under test the necessary voltage for the maximum period required.

It shall be capable of giving any output voltage between the limits of 1 kV and 50 kV. The waveform of the voltage shall be approximately sinusoidal, and during the test the peak value as would be determined by oscillograph or other approved method shall not exceed 1·45 times the r.m.s. value.

The frequency of the supply voltage, whenever possible, shall be 50 cycles per sec. In cases where it is not possible to operate at this frequency, the actual frequency of the test shall be specified.

Facilities for fine regulation of the output voltage are to be provided, and the voltage indicator shall be checked against calibrated sphere-gaps at frequent intervals.

(d) Method of Test.

A series of specimens shall be tested at a range of constant stresses such that in each case breakdown takes place before a time interval of 15 minutes has elapsed.

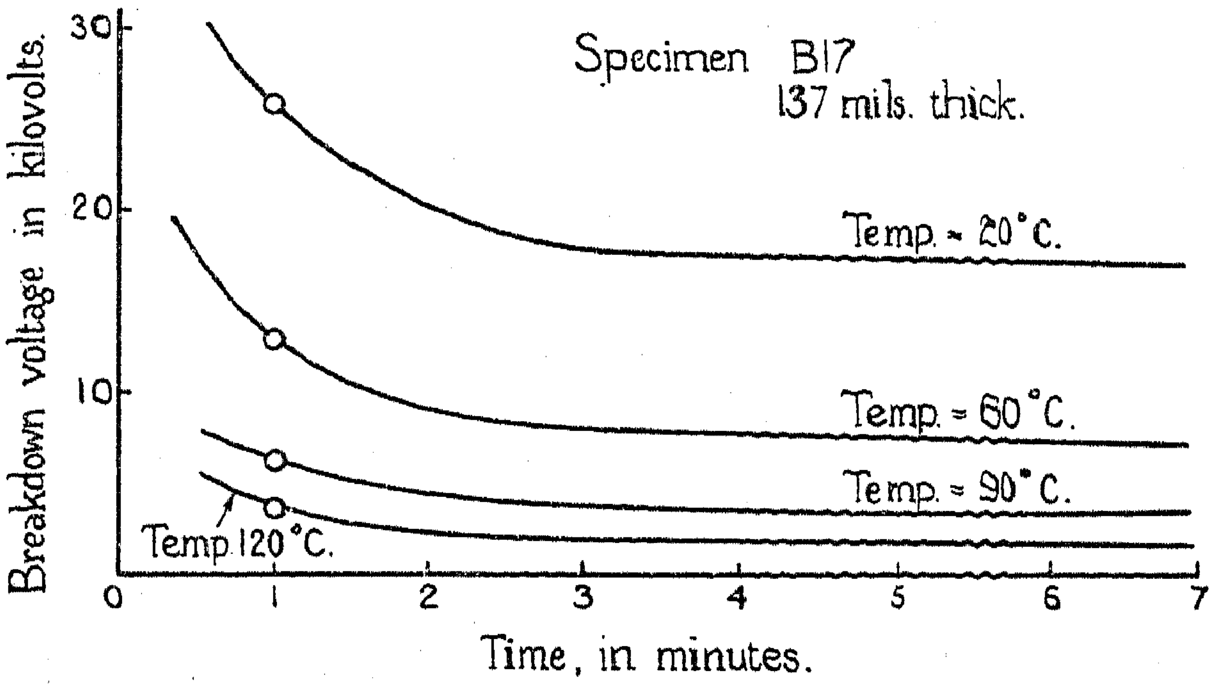

Fig. 7.—Time/voltage curves.

A curve shall then be plotted showing the relation between breakdown voltage and time for each of the following temperatures, 20° C., 60° C., 90° C., and 120° C., as shown in Fig. 7.

From these the 1-minute stress figures shall be calculated for each temperature, as shown in Table 1.

Table 1

One-Minute Breakdown Stress (Volts per Mil).

Specimen B.17 (137 Mils).

Temperature, ° C.	Stress, volts per mil
20	162
60	90
90	45
120	27

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* When the surface of the specimen is irregular or any difficulty is experienced in obtaining good contact, it is recommended that tinfoil should be interposed between the electrode specified and the dielectric.

Whenever convenient, these shall be plotted as shown in Fig. 8.

It is important that the conditioned specimens attain the temperature of the testing chamber before the test is commenced. The specimens and electrodes must therefore be maintained at that temperature for a sufficient length of time before test (see Appendix II; Table 3).

(7) POWER FACTOR AND PERMITTIVITY

The Association has given considerable attention, from time to time, to the subject of power loss in dielectrics,[*] and to methods for its determination. For most practical purposes it is sufficient to know the power factor and permittivity for any specified conditions. It is, however, recognized that such data are not convertible into actual watt-loss figures applicable to practical design problems. The reasons for this are given in report Ref. L/T26.[†] Nevertheless, a knowledge of power factor and permittivity is of value in choosing appropriate materials for use in locations where it is desirable to keep down the losses in the dielectric itself. Consequently reference is made below to existing instructions for their determination at power, audio, and radio frequencies.

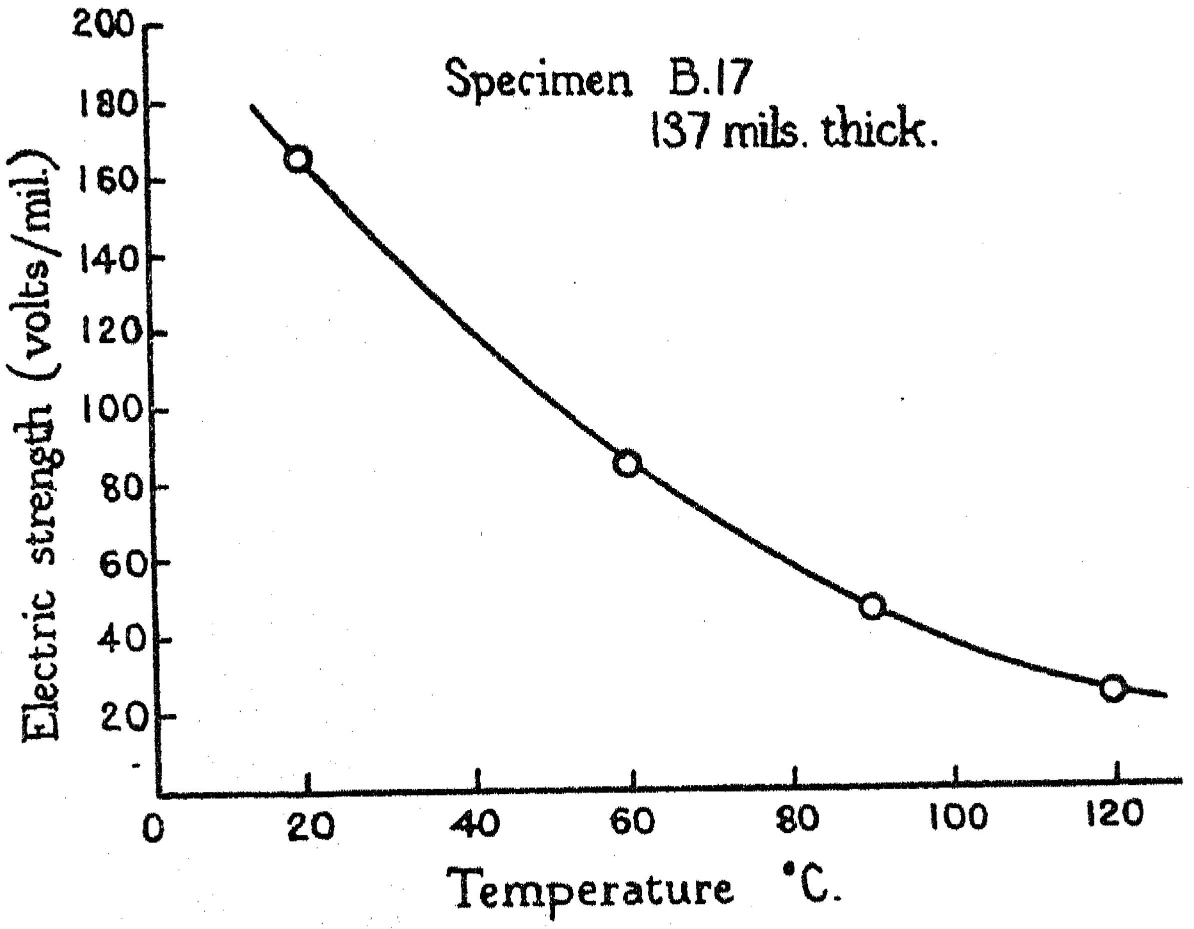

Fig. 8.—One-minute electric strength as a function of temperature.

The characteristics of various types of Schering bridge networks, including those involving the use of high-voltage low-frequency alternating current, as in industrial testing, are dealt with in Ref. L/T24.[‡] The more convenient low-voltage network, in which an ordinary telephone serves as detector (see B.S.S. No. 234[§]) is dealt with in Ref. L/T46,[||] while a survey of the various types of bridge networks suitable for use at radio frequencies, including those previously described by the Electrical Research Association in Appendix V of Ref. L/S2,[¶] is given in Ref. L/T56.[**]

(8) TENSILE STRENGTH

(a) Conditioning.

Before test the specimens shall be normalized in accordance with Clause 3.

(b) Specimens.

The following three alternative types of specimen may be employed according to the service requirements. The first specimen is intended to be moulded and may be adopted when the investigator is interested in the strength of mouldings. The second specimen is suitable for testing sheet material of any thickness or, if desired, may be moulded. The third specimen is applicable when the material is supplied in the form of rod. The third specimen may also be prepared from thick sheet, and in this case is suitable if it is known that the material does not vary in quality from the surface to the interior of the sheet or if interest is confined to the properties of the interior portions of the sheet. When testing rod

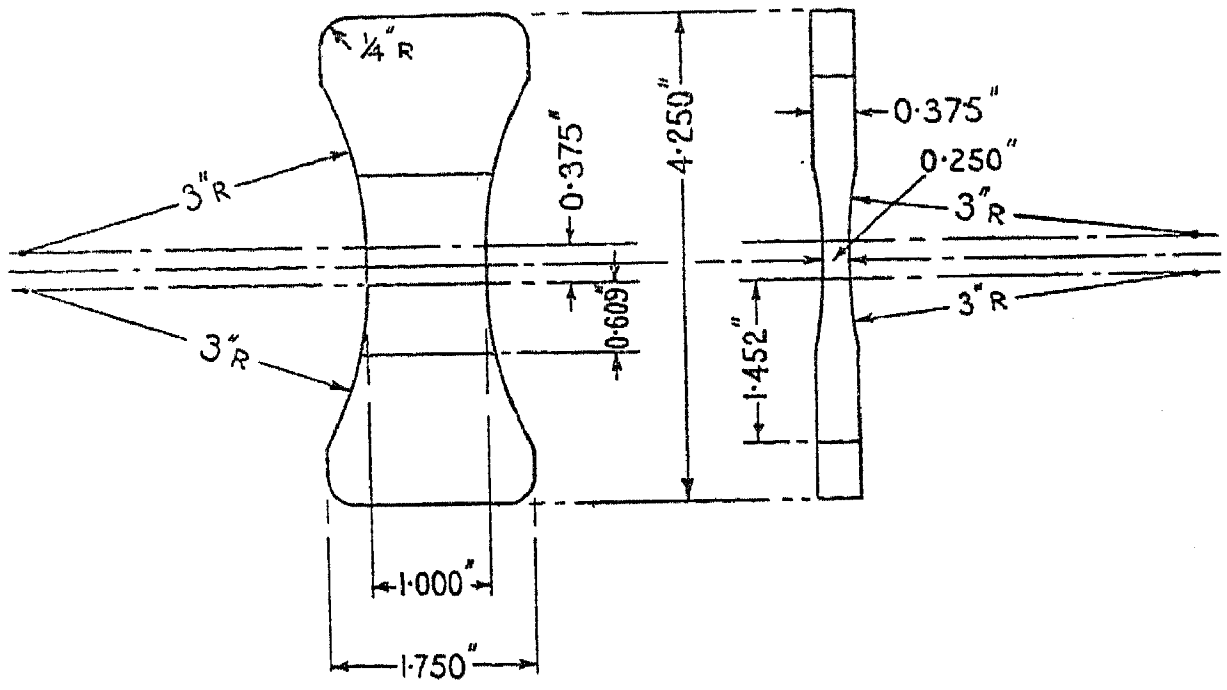

Fig. 9.—A.S.T.M. tensile test-piece.

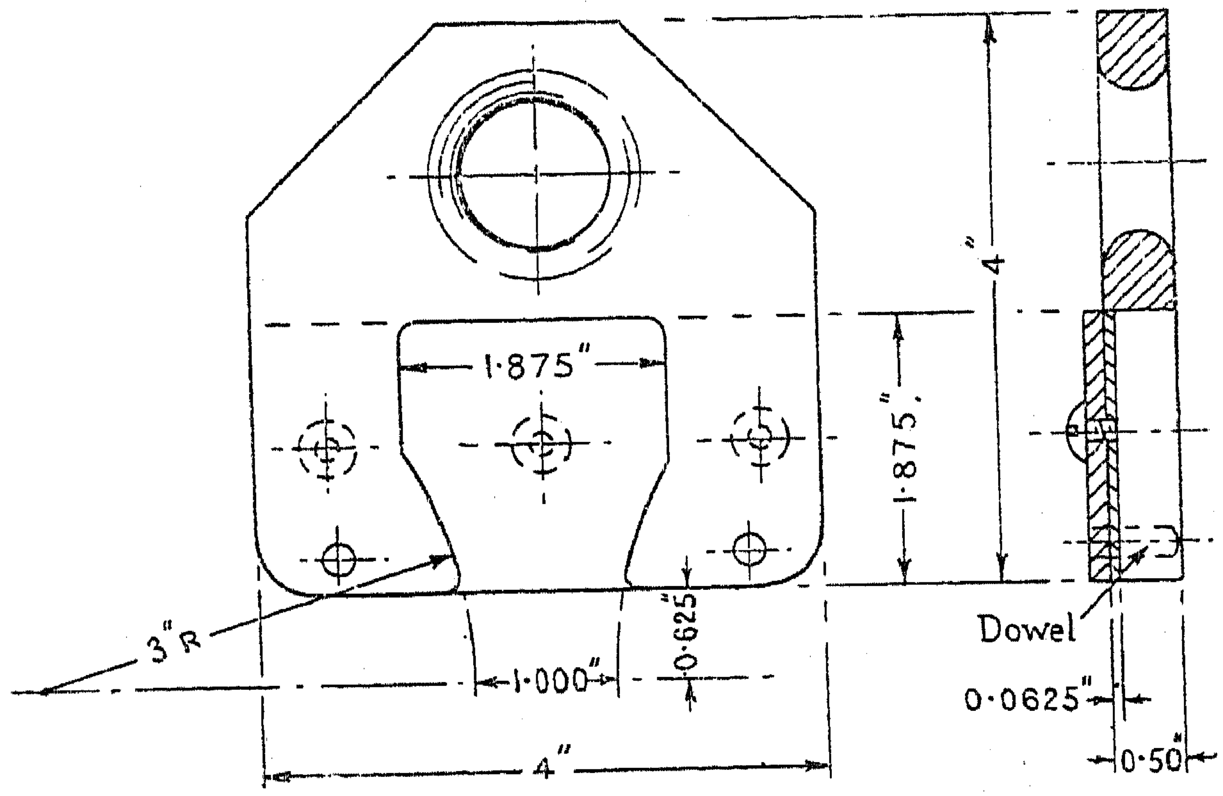

Fig. 10.—Holder for A.S.T.M. tensile test-piece. (Essential dimensions only are given.)

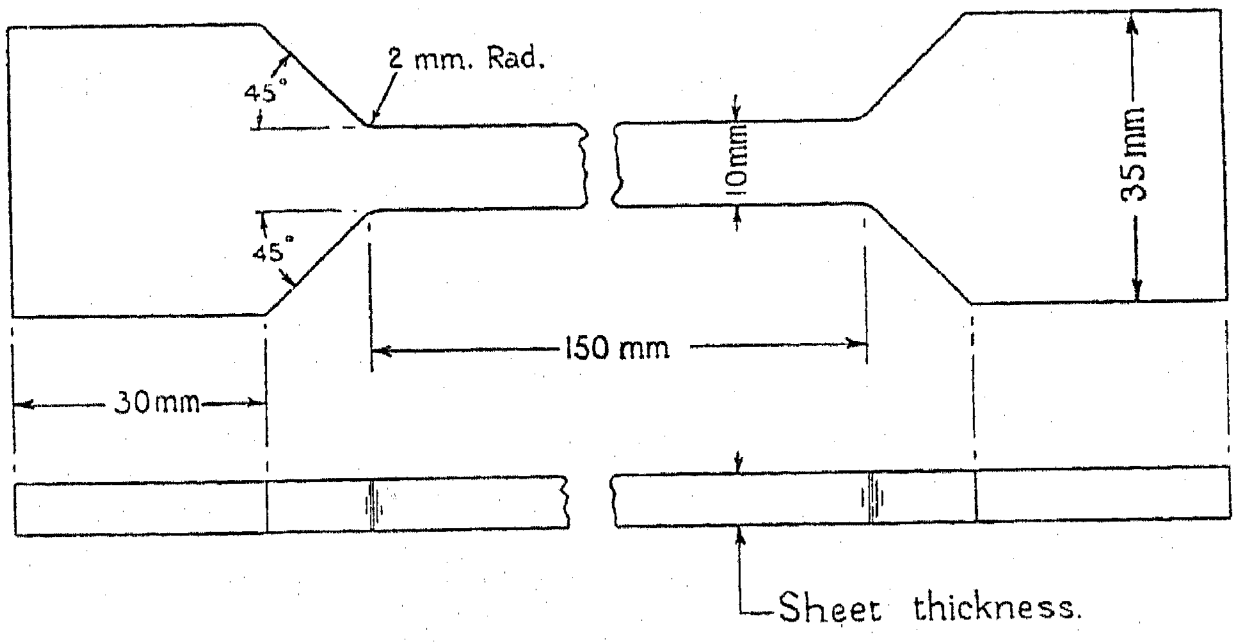

Fig. 11.—R.A.B.R.M. tensile test-piece.

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[*] See Bibliography, (12) and (13). [†] *Ibid.*, (14). [‡] *Ibid.*, (15).
[§] *Ibid.*, (16). [||] *Ibid.*, (17). [¶] *Ibid.*, (10). [**] *Ibid.*, (18).

the surface layers of the material must, of course, be removed.

(i) The A.S.T.M. standard test-piece for mouldings.*

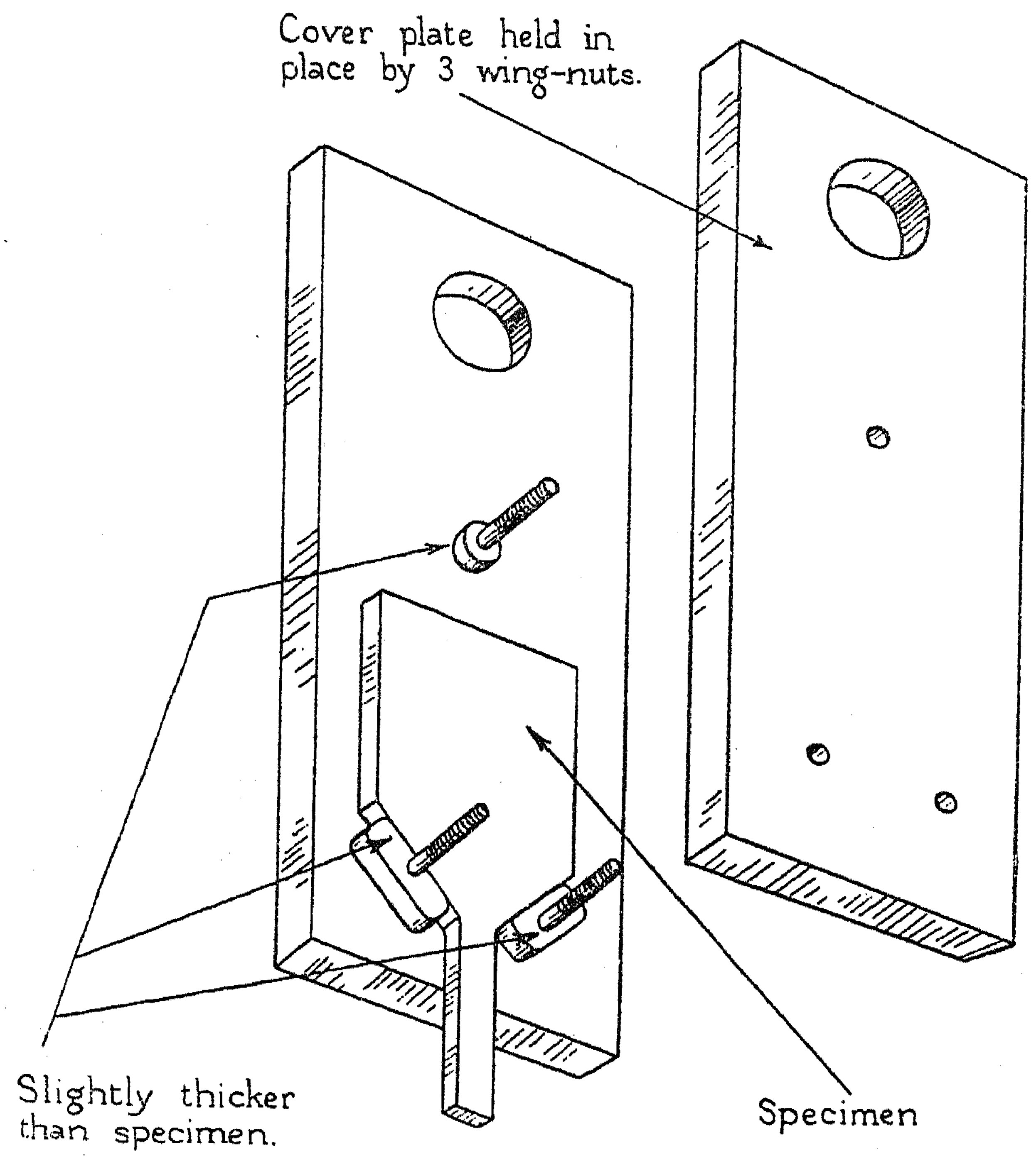
Cover plate held in place by 3 wing-nuts.
Slightly thicker than specimen.
Specimen

Fig. 12.—Suggested holder for R.A.B.R.M. tensile test-piece.

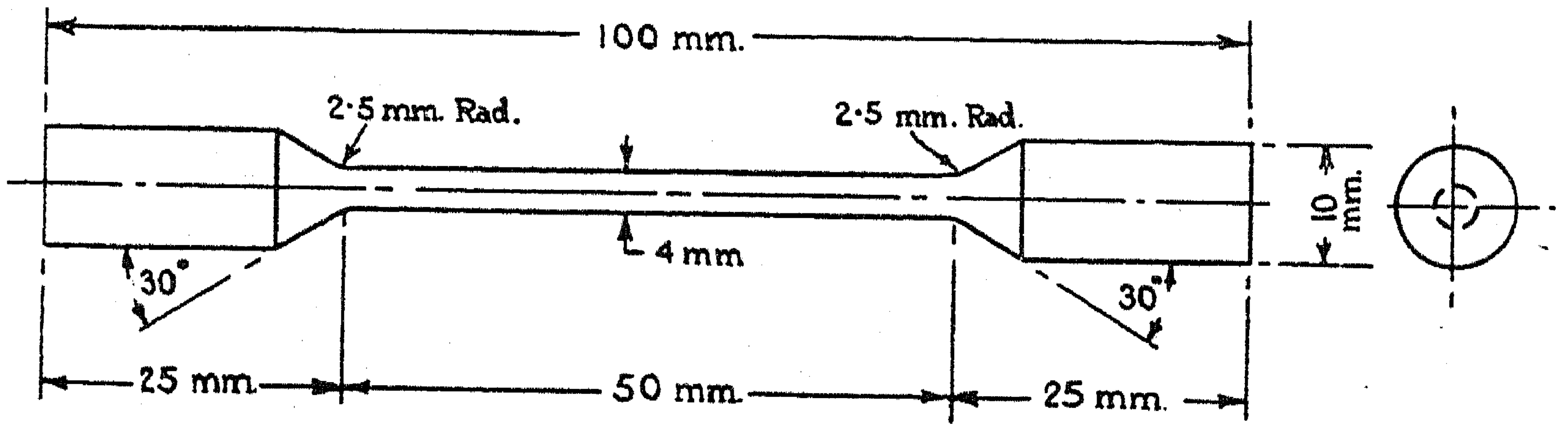

Fig. 13.—R.A.E. tensile test-piece.

This specimen shall be moulded to the form and dimensions shown in Fig. 9. Steel specimen holders as shown in Fig. 10 are required.

(ii) The test-piece adopted by the Research Association of British Rubber Manufacturers (R.A.B.R.M.) for sheet.†

The specimen shall be cut from sheet material to the form shown in Fig. 11. A suitable form of specimen holder, which automatically compensates for small inaccuracies in machining the shoulders of the test-piece, is illustrated in Fig. 12.

(iii) The form of test-piece used by the Royal Aircraft Establishment (R.A.E.)

This specimen, which is shown in Fig. 13, can be readily machined from thick sheet. A suitable form of specimen holder is shown in Fig. 14.

(c) Method of Test.

Any standard tensile testing machine having a suitable load range, the rate of loading or extension being adjustable, may be employed.

The specimen shall be tested at a uniform rate, the conditions of stress being adjusted so that rupture occurs in about 2 minutes. These conditions shall be determined by a preliminary test or calculated from previous knowledge of the approximate tensile strength. Variations in the breaking time of 15 seconds in either direction are permissible.

The maximum stress sustained by the specimen in this test before rupture occurs shall be observed and the tensile strength shall be calculated in pounds per sq. in. of original cross-sectional area.

It should be noted that the two methods of application of load (constant rate of loading and constant rate of extension) may give different results. The method adopted should therefore be stated. Comparisons will be dealt with in a separate report.

(9) CROSS-BREAKING STRENGTH

(a) Conditioning.

The specimen shall be "normalized" in accordance with Clause 3 before determining the cross-breaking strength.

(b) Specimen.

The specimen shall be a machined or moulded bar 100 mm. long and 15 mm. square section. Two such test-pieces may be obtained from a specimen moulded as in Clause 12 by cutting the latter specimen transversely into two portions of equal length.

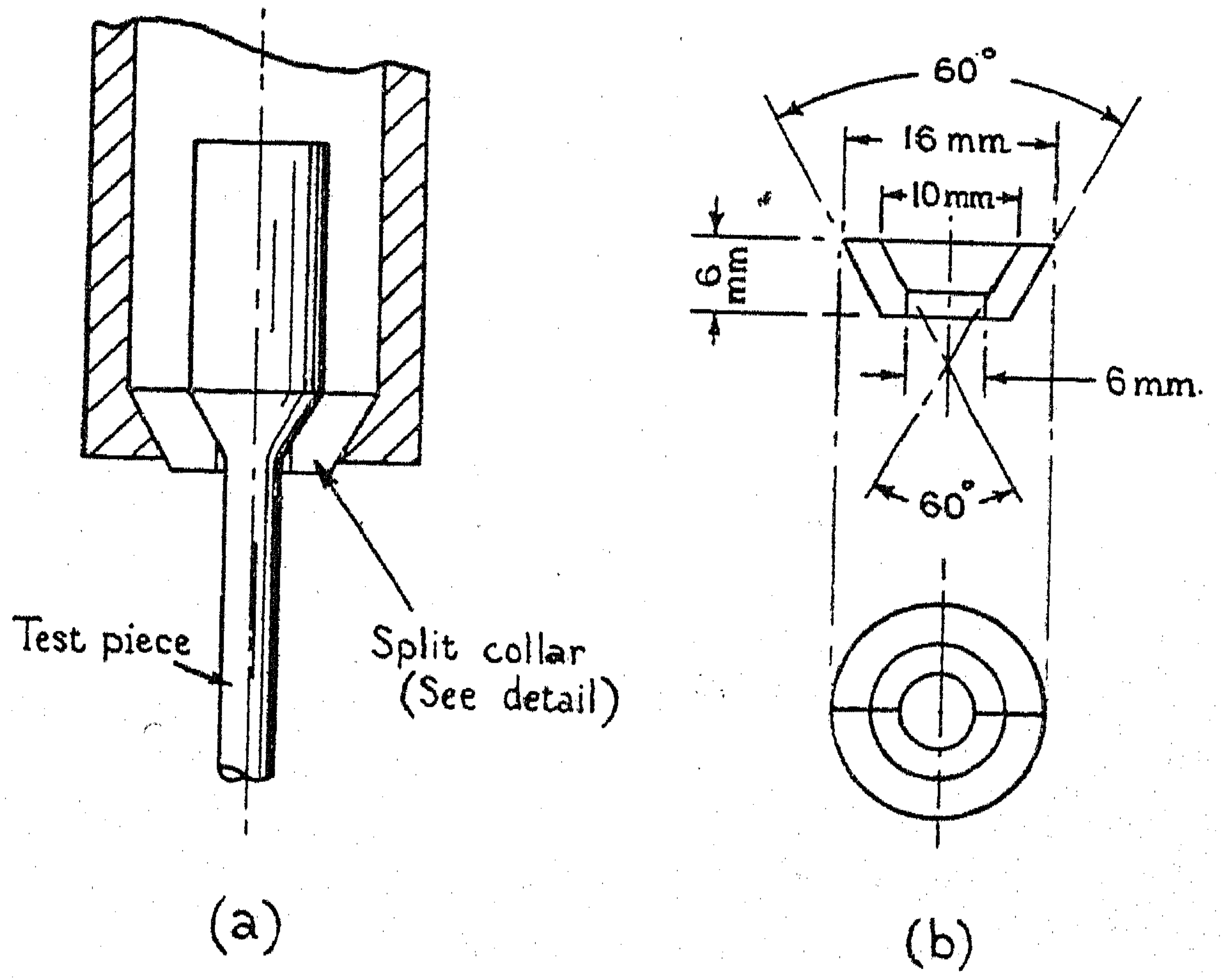

Fig. 14.—Holder for R.A.E. tensile test-piece.
(*a*) General view. (*b*) Detail of split collar.

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* See Bibliography, (19).

† *Ibid.*, (20).

(c) Method of Test.

The specimen shall be supported horizontally on two wedge-shaped supports, the axes of which shall be separated by a distance of 3 in. The points of the wedges on which the specimen rests shall be radiused to $\frac{1}{16}$ in. in each case. The load shall be supported on the specimen by means of a stirrup disposed symmetrically with respect to the supports, the point of contact of the stirrup with the specimen being in the form of a $\frac{1}{8}$-in. radius.

In cases where the cross-breaking strength of the specimen is thought to be high the load may be applied to the stirrup by a lever attachment giving a magnification of approximately eight to one. The rate of loading the specimen, although not of great importance, should not exceed 100 lb. per minute, but if it is necessary to employ specimens of smaller cross-section, the rate of loading must be adjusted accordingly.

(d) Calculation.

The cross-breaking strength in pounds per square inch may be calculated from the formula

$$C = \frac{3WL}{2BD^2}$$

where

C = cross-breaking strength in pounds per square inch,
W = breaking load in pounds,
B = breadth of specimen in inches,
D = thickness of specimen in inches,
L = distance between supports in inches.

If the dimensions are measured in centimetres the cross-breaking strength (C) in pounds per square inch may be calculated from the formula

$$C = \frac{9{\cdot}675WL}{BD^2}$$

(10) RESISTANCE TO CRUSHING

The ability of the material to resist crushing shall be proved at a temperature of 20° C. ± 5 deg. C. in a testing machine on a specimen moulded or machined to the shape and dimensions shown in Fig. 15. The end faces of the specimen shall be truly square, plane, and parallel, being rubbed down on fine emery paper if necessary, with due precaution against rounding.

If a specimen of the size shown in Fig. 15 cannot be cut from the material available, a smaller cylinder, geometrically similar, may be used, but not less than 10 mm. long and 10 mm. diameter.

An initial load of about 100 kg. per square centimetre shall be applied and the initial length of the specimen read under this load, in order to eliminate the compression due to bedding on the ends. The load ultimately registered shall include this initial load.

A series of loads shall then be applied to the specimen, a different specimen being used for each load, and the yield for each load shall be determined after 1 minute and 10 minutes respectively.

The yield shall be measured by the change of distance between the two compression surfaces by means of two direct-reading gauges, one on each side of the specimen, the mean of the two being taken, or, alternatively, the two gauges may be combined so as to give a single mean reading. A magnification of not less than 100 should be used.

For the 12-mm. specimen, the minimum load that gives a yield of 0·4 mm., when computed from the following formula, shall be deemed to be the crushing load

$$\text{Yield} = y + \frac{0{\cdot}25y}{y'}$$

where y and y' are the yields in millimetres at 10 minutes and 1 minute respectively. When the dimensions of the specimen are less than 12 mm. the permissible yield shall be reduced in proportion.

(11) IMPACT STRENGTH

The most recent recommendations of the E.R.A. on the subject of impact strength testing are contained in an unpublished report Ref. A/S36,* which will shortly be made generally available.

(12) PLASTIC YIELD

The following test is designed primarily to provide a basis for the comparison of the resistance to plastic yield offered by sheet, rod or moulded insulating materials at elevated temperatures, and is based upon the results of an extensive experimental investigation by the E.R.A.†

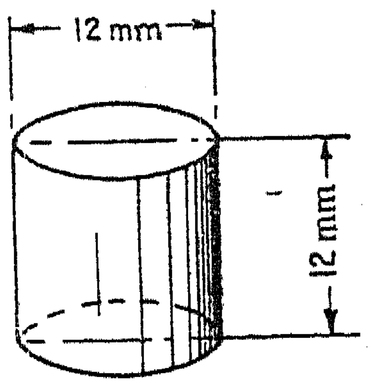

Fig. 15.—Resistance-to-crushing test specimen.

The values obtained by this test are not to be considered as indicating safe working temperatures, which, in fact, can only be determined definitely by tests on finished parts under service conditions. However, the applied stress, deflection, and time of test specified, have been carefully chosen as a result of extensive investigations so as to yield approximately the safe maximum working temperatures in the majority of cases where moderate mechanical stresses are supported by the part concerned, provided, of course, that all other properties, such as electric strength, resistance, etc., are also maintained satisfactorily.

(a) Definition.

The temperature as determined according to the test described below is referred to as the Yield Temperature.

(b) Method of Test.

The test shall be made on a specimen of the shape and dimensions shown in Fig. 16. When it is impracticable to obtain specimens of this size, the test may be carried out on smaller or larger specimens, provided certain modifications are made, which are described below.

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* See Bibliography, (21).

‡ *Ibid.*, (7).

The test shall be carried out in an oven maintained at a constant temperature. The oven shall be of substantial construction with well-lagged walls, so that its thermal capacity considerably exceeds that of the specimen and clamps. The oven shall be brought to a suitable predetermined temperature, and the specimen, fixed in clamps, but without load, shall be placed in position as rapidly as possible. The stirrup by which the load is applied to the specimen shall preferably carry a steel wire passing vertically down through a hole in the bottom of the oven and carrying a pan (see Fig. 17). By this means the load can be applied to the specimen by placing weights in the pan without the necessity of opening the oven door. The clearance between the sides of the specimen and stirrup shall not exceed 0·5 mm.

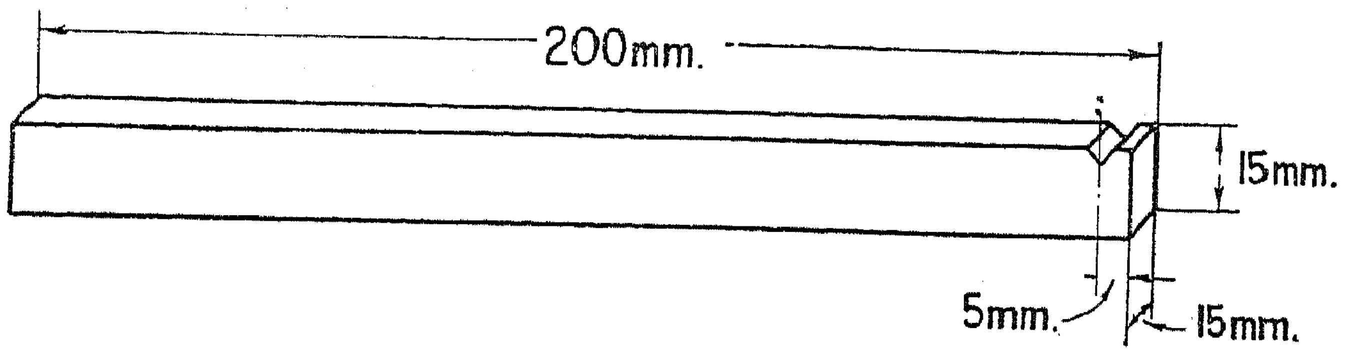

Fig. 16.—Specimen for plastic yield test machined from sheet or rod, or moulded.

Fifteen minutes after the specimen has been placed in the oven a reading of the height of the line of contact of stirrup and specimen shall be taken and then a load of 450 g., including stirrup and pan, shall be applied. The specimen shall be maintained thus at a constant temperature for 6 hours, at the end of which period, and whilst still hot, the height shall be remeasured with the load on.

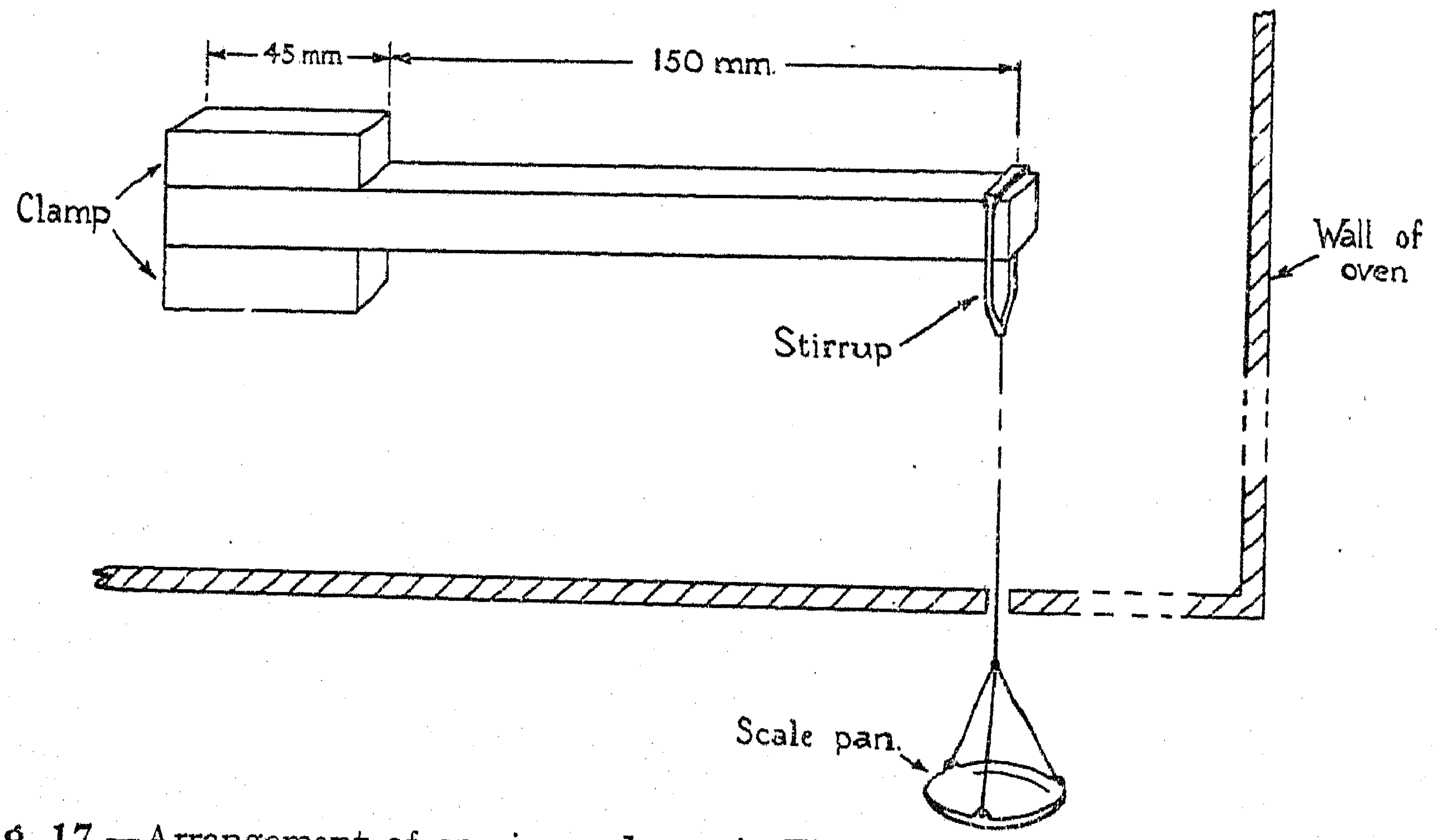

Fig. 17.—Arrangement of specimen shown in Fig. 16. Set-up for plastic yield test.

The test shall be repeated at other suitable temperatures to enable a deflection/temperature curve to be drawn. From this curve the temperature corresponding to a deflection of 5 mm. shall be interpolated and shall be taken as the Yield Temperature. There shall be at least two experimental points above and below the Yield Temperature from which one experimental point shall differ by not more than 5 deg. C.

(c) Tests on Non-Standard Specimens.

In the case of smaller or larger size specimens, it is necessary that both the load and deflection be adjusted in accordance with the following equation, to give equivalent results. In all cases the length of the specimen must be considerably greater than the cross-sectional dimensions.

The load shall be given by

$$W = \frac{20BD^2}{L}$$

where

W = total load applied in grammes,
B = horizontal breadth of specimen in millimetres,
D = vertical thickness of specimen in millimetres, and
L = leverage in millimetres (distance of stirrup from clamp).

The deflection corresponding to the Yield Temperature shall be given by

$$h = \frac{L^2}{300D}$$

where h = deflection in mm.

(d) Auxiliary Test.

In the case where the material is unfamiliar it is advisable to have an approximate idea of the Yield Temperature in order to avoid an unnecessary number of preliminary random constant-temperature tests. This may be obtained as follows:—

The specimen shall be fixed in clamps in the oven at room temperature. A load of 1 350 g. (or, if a non-standard test-piece is employed, a load having three times the magnitude of that calculated to be required in the stationary temperature tests) shall be applied and a measurement made of the position of the unsupported end of the bar as above. The temperature of the oven shall then be raised at an approximately uniform rate of 60 deg. C. per hour. The temperature at which the deflection of the bar corresponds to 5 mm. (or, with non-standard test-pieces, the value of *h* calculated as above) shall be observed.

This value of temperature does not, in the majority of cases, differ very much from the Yield Temperature, but this test is in no case to be considered determinative.

(13) ACCELERATED AGEING

It is known that some materials deteriorate by prolonged heating, particularly in the presence of air, this treatment causing or accelerating chemical and physical changes. Where such deterioration has occurred, evidence of it will generally be found in a change of certain properties observable at normal temperature. The change is likely to result in a loss of mechanical strength, and for its observance it is desirable, therefore, to select a mechanical test which is both readily made and gives uniform results. Examination of the available test records shows that the cross-breaking strength test (Clause 9) gives very uniform results and the use of this test is recommended for research on ageing. However, where impact strength is important, this property is preferred since ageing tests on some materials have shown that impact strength may fall rapidly while cross-breaking strength is maintained.* The materials for this test should be aged in the form of test specimens, not as sheet and afterwards machined, since impact strength may be very sensitive to surface oxidation.

In some cases the conditions of service are such as to give electric strength a greater relative importance than mechanical strength. In these circumstances a comparison of the results of electric strength tests (Clause 6), taken before and after the prescribed heat treatment, should be made.

For these tests the specimens shall be maintained at a specified temperature for a given time in air, or shall be submitted to cyclic changes of temperature or temperature and humidity, after which they shall be allowed to cool to a temperature between 15° C. and 25° C. before applying the mechanical or electrical tests. Details of the ageing treatment are to be fixed by the user.

(14) DENSITY

When density (mass per unit volume) is an important factor in the choice of a material, it shall be determined at 20° C. and shall be expressed in grammes per cubic centimetre. In all cases where the dimensions are accurately known, the density can be determined without immersion. In cases where the specimen is too irregular or too small for accurate volumetric determinations to be made, the standard "displacement" method may be used. For the present purpose the density of water at 20° C. shall be taken as $0{\cdot}998_3$.

(15) WATER ABSORPTION

A specimen 5 cm. in diameter and 1 cm. thick shall be dried at a temperature of 50° C. until it ceases to lose weight. It shall then be cooled in a desiccator and weighed with the usual precautions, after which it shall be immersed in water at room temperature for 24 hours. The specimen shall then be taken from the water and, after removing the surface moisture by wiping, weighed again. The weight shall be taken to the nearest milligramme in each case. The difference between these two weights gives the weight of water absorbed. Changes in dimensions shall also be observed.

The period specified above (viz. 24 hours) is suitable for rapid comparisons only. For research purposes a longer period must be adopted and time/absorption curves and time/dimensional-change curves plotted, up to saturation point, whenever practicable.

It is important that the period of immersion should always be stated when reporting results of tests.

(16) MACHINING PROPERTIES

In Ref. B/S1,* which this report supersedes, the Association made recommendations for the determination of the tooling characteristics of hard composite materials and for grading them with respect to chipping when machined in a particular manner. Although these recommendations were based on a considerable amount of practical experience, much of which has already been placed on record,† there is no evidence that they have been adopted by the industry.

It has been contended that the machining of hard composite materials permits the exercise of considerable individuality which it is prudent not to rule out by too closely specifying the method to be used. As soon as latitude is introduced into the method of machining, it becomes impossible to grade materials for any particular reaction thereto. Consequently no attempt will be made to review, revise, or supersede, the existing E.R.A. references to tool-wear and chipping until there is clear evidence of a demand for such information.

The reader is referred to a comprehensive series of articles in *British Plastics*, dealing with the machining of plastics.‡

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* See Bibliography, (22).

* See Bibliography, (1).

† *Ibid.*, (23).

‡ *Ibid.*, (24).

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(13) "Dielectric Phenomena. Vol. III: Breakdown of Solid Dielectrics, by S. Whitehead, M.A." E.R.A. Ref. L/T42. (Published by Benn Bros.)

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(15) "Notes on the Theory and Use of the Schering Bridge in Power Loss Observations." E.R.A. Ref. L/T24.

(16) "British Standard Specification for Ebonite for Electrical Purposes." B.S.S. No. 234, 1933.

(17) "A Simplified Bridge-Network for the Determination of Dielectric Power Loss, by W. D. Owen." E.R.A. Ref. L/T46.

(18) "A Critical Résumé upon High-Frequency Bridge Networks, by T. I. Jones (N.P.L.)." E.R.A. Ref. L/T56.

(19) "Standard Methods of Testing Molded Materials used for Electrical Insulation." A.S.T.M. Designation: D48–33. *A.S.T.M. Standards*, 1933, part ii, p. 1097.

(20) "The Properties of Hard Rubber (Ebonite). Influence of Rubber-Sulphur Ratio and Vulcanization Time on the Properties of Pure Rubber-Sulphur Compositions, by H. F. Church, B.Sc., and H. A. Daynes, D.Sc., F.Inst.P., F.I.R.I." E.R.A. Ref. B/T16.

(21) "Directions for the Determination of Impact Strength of Composite and Fibrous Insulating Materials (superseding Ref. A/S33)." E.R.A. Ref. A/S36.

(22) "Experiments on the Ageing of Hard Rubber, by H. F. Church, B.Sc., and H. A. Daynes, D.Sc., F.Inst.P., F.I.R.I." E.R.A. Ref. B/T14.

(23) "Report on Hard Composite Dielectrics, their Electrical and Mechanical Properties." E.R.A. Ref. B/T2.

(24) "The Machining of Non-Metallic Materials," by W. Phillips and H. T. Richardson. *British Plastics*, January to June 1932.

APPENDIX I

Notes on Conditioning Chambers and their Equipment.

(a) Construction.

(i) *Cold Chambers.*

For conditioning, or test chambers which are not required to be heated, a satisfactory and convenient method of construction is to make the chamber of $\frac{3}{4}$-in. tongued and grooved boards and to line the inside with thin sheet metal. The latter should be soldered along all joints such as those occurring where the sides meet the top and bottom. The use of a sheet-metal lining is essential when it is required to employ the chamber for very high or very low humidities.

The use of rubber gauntlets fastened in the sides of the chamber permits the investigator to change the connections and manipulate the samples without opening the chamber. A glass window at the top ensures good illumination of the interior, by either day or artificial light.

(ii) *Hot Chambers.*

When a chamber is required for temperatures above those of the laboratory, an electrically heated oven having double walls of sheet metal with the interspace suitably packed is recommended.

With a view to obtaining as uniform a temperature as possible, the heating elements should be distributed over the whole of the bottom of the oven and the temperature regulated by means of an external resistance. To obtain a wider variation of temperature series parallel connections can be employed, provided all the units are left in circuit. If the specimens and internal fittings are suitably arranged, the convection currents, set up by the heating elements, will be sufficient to keep the temperature and humidity in different parts of the chamber as uniform as is necessary.

(b) Temperature Control.

Automatic control of temperature to within plus or minus 1 deg. C. is achieved, without difficulty, by means of thermostats controlling electrical contacts in the heater circuit (if electrical) or mechanically controlled regulating devices in cases where other than electrical heating is employed.

It is important that the thermostat contacts should be outside the chamber.

(c) Humidity Control.

(i) *Normal Condition.*

A simple method of producing an atmosphere of 75 % relative humidity at normal room temperatures (15–25° C.) is to circulate the air in the chamber in such a manner as to cause it to pass across a tray of wet salt (NaCl) crystals. The surface area of the salt should be as large as possible.

(ii) *Conditions other than Normal.*

Varying degrees of humidity, between the limits of 40 % and 90 %, can be obtained without difficulty by the use of a solution of calcium chloride made up in accordance with Table 2.

Table 2

Relative humidity, per cent	Density at 15° C., grammes per cm³
90	1·121
80	1·195
70	1·252
60	1·302
50	1·349
40	1·395

The 1·395 density solution will begin to deposit solid at 10–15° C. A relative humidity of 33–34 % is obtained by the use of moist crystals of calcium chloride ($CaCl_2 6H_2O$) or of magnesium chloride ($MgCl_2 6H_2O$) kept just moist, i.e. by films of saturated solution. For a humidity of 75 % the wet salt (NaCl) crystals mentioned above have the advantage of offering more surface and requiring less attention.

(iii) *Relative Humidity of Approximately* 100 % (*Saturation*).

Even when a large area of water is freely exposed in a chamber with walls of a non-absorptive material, it is impracticable to obtain a relative humidity exceeding 95 % unless the air is continually stirred so as to pass over the surface of the exposed water. In these circumstances a humidity of 96–98 % is obtained without difficulty, except when the temperature exceeds 25° C.

(iv) *High Humidities at High Temperatures.*

In cases where it is desired to study the properties of dielectrics under "tropical" conditions (viz. relative humidity of 90 % and temperature of 50° C.) it may be found necessary to inject water vapour into the chamber from a separate vaporizer, the flow being controlled by a hygrostat.

(d) Measurement of Humidity.

(i) *Wet- and Dry-Bulb Hygrometers.*

The wet- and dry-bulb hygrometer is an unreliable instrument if used in still air, but by ensuring that the velocity of the air past the bulb is of the order of 3 m. per second it can be converted into an instrument of satisfactory precision. In the chamber employed a window is provided in one side through which the thermometers can be read. This arrangement has been found very convenient.

If for any reason an air velocity past the bulbs of at least 3 m. per second cannot be ensured a dew-point hygrometer should be used. The surface on which the deposit occurs should be of well-burnished silver, and the usual aspiration method through ether, alcohol, or water can be used for producing the necessary lowering of temperature.

When temperature differences are small it is important that the fluid be in actual contact with the silver surface if accurate results are required. The temperature gradient through the glass, if a silver thimble is fitted on to a test tube in the usual manner, may be of importance, and the temperature of the fluid will be appreciably lower than that of the silver surface, giving too low a value of the estimated humidity.

(ii) *Hygrostats.*

For the automatic control of humidity, as proposed in (*c*) (iv) above, it is necessary to make use of a device which will open and close an electrical circuit at prearranged values of humidity. Hair hygrometers fitted with adjustable maximum and minimum electric contacts have been found satisfactory for this operation. With suitable auxiliary apparatus (viz. vaporizer with relay-controlled heater and impeller or air-flow device) the humidity can be controlled to within ± 2 %.

APPENDIX II

The time periods given in Table 3 are allowed for bringing conditioned specimens to the temperature at which it is required to determine the electric strength when the material is to be tested (*a*) in air, and (*b*) under oil.

Suitable periods are indicated for various temperature differences between the conditioning and testing chambers. The figures given apply to the case in which specimens up to ½ in. in thickness are placed between 3-in. and 1½-in. brass discs for the electric strength test.

Table 3

	Time periods for the following temperature differences:—				
	40 deg. C.	70 deg. C.	100 deg. C.	130 deg. C.	160 deg. C.
(*a*) In air	mins. 5	mins. 5	mins. 10	mins. 10	mins. 10
(*b*) Under oil	5	10	15	15	15

Table 4

Details of Temperature, Time, and Humidity, to be used for Conditioning the Classes of Dielectrics covered by this Report, previous to the Determination of their Electric Strength.

Condition	Temperature, °C.	Time, hours	Humidity (relative)* %	Means of humidity control
Normal	15–25	18–24	75	Wet salt (NaCl) crystals
Very dry	120–130	18–24	†	—
Dry	75–80	18–24	†	—
Damp	15–25	18–24	Approximately 95	Water only
Tropical	45–50 during the day (8 hours) and 15–25 during the night (16 hours)		Approximately 90 during the day. Saturated‡ during night	Water only
Chemically treated§	15–25	168 (1 week)	—	—

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* For notes on the construction of conditioning chambers and the measurement of humidities therein, see Appendix I.

† Air at ordinary temperature and humidity is to be heated to the temperature specified, without any artificial drying or humidifying.

‡ The cubic capacity of the conditioning chamber compared with its internal area and the total area of the specimens must be such that a liberal condensation of moisture occurs on the latter during the low-temperature period.

§ The treatment to be given will depend on the purpose for which the material is required, the following being employed:—

(i) If exposed to rain or water	Distilled water.
(ii) If exposed to sea water	10 per cent solution of salt in distilled water.
(iii) If exposed to acid	Sulphuric acid, specific gravity 1·25 at 15° C.
(iv) If exposed to alkalies	10 per cent solution of caustic soda.
(v) If exposed to ozone	Treatment to be given is under consideration.
(vi) If exposed to ultra-violet light	
(vii) If exposed outdoors	

DISCUSSION ON
"THE ELECTRIC SUPPLY SYSTEM IN BERLIN"*

WESTERN CENTRE, AT GLOUCESTER, 11TH JANUARY, 1937

Mr. W. A. H. Parker: I am particularly interested in the typical load curves of Fig. 2, because they show the same characteristics as those of a large city in this country. I notice that the peak loads are taken by means of steam from Ruths accumulators, and it would be interesting to know whether the capital and maintenance charges on this plant have justified its installation.

Several departments of the Bewag have divided control in that they are controlled by the technical and commercial general managers, and I should be interested to know whether any real benefits are derived from such an arrangement and also whether the two general managers receive similar salaries. It appears that domestic sales are not considered of sufficient importance to warrant a separate department but are included under power sales.

As a result of centralization the Bewag are able to afford research laboratories and facilities for carrying out investigations under service conditions. Do these include certification of apparatus used on consumers' premises? Such work is of great importance to the supply authority and its consumers.

Mr. A. H. McQueen: The author mentions the rapid development of the expansion switch; perhaps he would give us the reasons leading to the adoption of this type of breaker. Research has been carried out in England on the expansion circuit-breaker, but it has not been found possible to meet all the requirements dictated by usage. British engineers have not, however, lost sight of German practice. Oil-immersed metalclad switchgear is being used successfully in this country, and there is no advantage in adopting other designs.

Mr. L. F. A. Driscoll: Sectional diagrams of the typical air and water expansion switches referred to in the paper would be most interesting.

A striking feature of Table 1 is that the installed capacity of each station except Steglitz (6 600 kW) is nearly as large as that of many of the selected stations on the grid system. For example, the plant capacities of Liverpool and Cardiff are 130 000 and 33 000 kW respectively for the period in question, as compared with the 270 000 and 224 000 kW for Klingenberg and Kraftwerk West respectively. Will the author please state the average fuel consumption per unit and the thermal efficiencies of the German stations mentioned in Table 1?

The use of pass-out steam from turbines is no novelty; it is extensively used in Russia, as was explained by Mr. Monkhouse† before this Centre in 1935. Perhaps the author could give us some idea of the Berlin tariffs, particularly the revenue and cost per unit sold and the basis of charging for steam heating.

Mr. A. A. Beckingsale: The author frequently refers to the central control room; I should be interested to learn more details of this, particularly as to what remote indications and operations are received and originated from it. Are public or private communication circuits used?

Mr. R. W. Biles: It is of considerable interest to see that the Bewag utilize impedance protection on a cable system of comparatively short lengths. Up to now, the manufacturers in this country have not been able to provide relays of sufficient accuracy to give adequate time-spacing over such short lengths of overhead line, let alone on a cable system. It may be that the Bewag system overcomes this difficulty by employing feeder reactors. Perhaps the author could throw some light on this matter.

The use of the Petersen coil in this country is extending, and I gather that the Bewag system is earthed through iron-cored reactors at numerous points of the system. The question arises as to how the correct balance is maintained when parts of the distribution system are taken out of commission. I believe this is one of the principal objections to the use of the system in this country. Once this side of the question is fully understood by engineers, I think the Petersen-coil method of earthing will have a wider application.

Apparently the reason why the Bewag changed over from the neutral-resistance to the Petersen-coil method of earthing was the excessive voltage-rises experienced throughout the system during fault disturbances. About 1924 a 66 000-volt system in Paris gave similar trouble, and breakdowns occurred at numerous points along the cable routes owing to arcing between lead-sheaths burning holes in the latter. Similar trouble was experienced on the pilot cables. These troubles were found to be due to inadequate bonding of the cables along the routes and at each end, and it has occurred to me that a similar lack of bonding may have been the cause of the trouble in Berlin.

It is of interest to note the extensive use of pilot cables for remote-control purposes rather than for self-contained protective systems. The use of the latter would appear to relieve the control engineer of responsibility in cases of emergency, and ample staffing at the control centre probably overcomes this difficulty.

Mr. W. Hill: With regard to the Petersen coils, how is the difficulty got over of altering the tappings that are obviously necessary as the system is extended and as parts of the system are put in and out of action?

The author stated in his verbal summary of the paper that a voltage of 220 volts had been adopted for the low-voltage grid, and that there were certain special technical difficulties to be got over which do not arise on the 110-volt grid systems used in America. Would he tell us some of these difficulties?

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* Paper by Mr. M. W. H. Davies (see vol. 80, page 305).

† *Journal I.E.E.*, 1935, vol. 76, p. 601.

I understand that the Bewag rely on a reverse feed into the 33-kV system for the operation of switchgear on this system under fault conditions. Considering the large ratio of the transformers and the comparatively small size of some, I should like more information as to how they manage to get operation on what must be very small currents.

I cannot see how the differential choke operates on the low-voltage grid, and I should be glad of some more information on this point.

It appears that the Bewag are allowed to carry out quite an elaborate system of multiple earthing on the h.t. system which would obviously be frowned on in this country.

[The author's reply to this discussion will be found on page 567.]

WESTERN CENTRE, AT PLYMOUTH, 19TH APRIL, 1937

Mr. C. J. Hocking: The main advantage of the distribution scheme adopted in Berlin over systems laid down in this country would appear to be that the copper in the l.t. network is used in such a manner that the voltage-drop to any consumer is a minimum and that continuity of supply to consumers supplied direct from the l.t. network is better than is possible with the more usual type of system.

In order to provide good voltage regulation and continuity of supply from any l.t. network it is essential that a fault on the h.t. system be isolated and the feeding of the remainder of the system be adjusted without delay. Whilst the tendency for low voltage to occur on the l.t. grid system in Berlin is not likely to be as serious as on a normal British system, it will still be present, and I am rather surprised that supervisory control of a greater number of h.t. switches has not been adopted in Berlin.

Each grid appears to cover a comparatively large area; if, therefore, a total failure of supply occurred during a peak-load period it would appear to be a serious matter, in view of the fact that, at the moment the grid is made alive, the full load on the grid together with any fault current must be carried by an h.t. switch, unless means are provided to synchronize the closing of a number of switches feeding each grid.

I shall be glad to know whether the author can supply any information regarding the experiences of the engineers engaged in the operation of the system, particularly in cases where a complete shutdown of a grid has taken place during a peak-load period.

Mr. W. A. Crocker: Is the compound in the 380-volt cable of a special nature designed to assist in sealing after a fault, or is standard cable employed? Have any street explosions been experienced, causing lifting of pavements or joint-box covers, owing to the evolution of gas? What type of cut-out is employed in consumers' premises to deal with the short-circuit currents, which, I presume, will be somewhat high at all points of the solid 380-volt network? The author has stated that the transformer capacity in each 380-volt substation is one-third in excess of the load; I am surprised, in view of the rate of increase in load and the low cost of increased transformer capacity relative to the rest of the equipment, that a greater margin is not allowed.

Mr. H. Midgley: One of the most interesting features in the description of the Berlin undertaking is the solid l.t. network or grid, and I should like to ask some questions relating to the operation of this.

First, it is assumed that all these cables are paper-insulated, and therefore no question arises of dealing with faults on vulcanized bitumen cables. Can the author confirm this?

Second, are any of the cables laid in ducts, and, if so, is there any tendency for a burn-out to travel along such a duct? If a workman strikes a live cable with a pick or iron bar is there any more danger than would arise in the case of the usual type of fused and sectionalized network?

Third, how are the positions of faults located during the annual testing of cables; and are repairs carried out on live cables or has the supply to be cut off for location and repair of faults?

Fourth, it has been found in some electricity undertakings that the congestion in streets, due to the large number of cables, has necessitated the adoption of 33 000-volt cables instead of 6 600-volt cables; has this condition arisen in the Berlin undertaking?

Finally, I note that compressed-air operation of oil switches has been adopted in certain stations. It is stated that this means a saving in the cost of pilot cables and in battery costs; but is it sufficiently quick in operation to be suitable for synchronizing switches where long runs from switches to control boards are involved?

Mr. T. W. Mackay: I cannot avoid thinking that the general layout of the entire Berlin system is designed with a definitely political and military significance behind it, and in that respect I would encourage supply engineers in this country to review the conditions of their own undertakings under modern warfare conditions. One of the outstanding features of the Berlin distribution scheme is the solid l.t. system, which, to my way of thinking, is only a practical proposition provided the network is separated at certain points and is fed by a number of relatively small-rated transformers having fairly high reactance values so that the fault current may be limited to fairly narrow bounds. If such is not the case, I can picture a very alarming condition in a city street where a sustained electrical fault fused a gas main.

The use of the impedance relay is of interest; as the name implies, a definite amount of impedance is required in the fault circuit in order to obtain selective discrimination. In ordinary high-voltage transmission work the particular value is expressed in terms of distance, and unless there is separation of at least 10 miles between the relay stations this particular form of protection will not be very effective or reliable in actual practice.

One point that I would criticize is the use of centre-tapped reactors that are placed on the output side of the l.t. transformers. I assume that the particular instrument employed on the Berlin system is a simple, one-window core, having the load windings of equal turns wound on each core in opposition; thus, when the loads on the two limbs are equal, the ampere-turns or m.m.f.'s are equal and opposite, therefore there is no flux threading the iron circuit. It will be apparent that under such circumstances, which are ideal and not likely to arise in practice, apart from a small leakage-reactance voltage loss the reactor is almost fully compensated and the major voltage-drop across the windings is due to the *RI* drop, conditions being very similar to those in a direct-current winding. Immediately the output load is unbalanced, however, the m.m.f. on the loaded limb predominates and circulates a flux through the iron core, reversing the polarity of the other core and immediately introducing an active e.m.f. into the less heavily loaded circuit. The induced e.m.f. operates with a certain phase displacement to oppose the line voltage, and behaves like an ordinary a.c. booster "bucking" the busbar voltage. The above action does not go on indefinitely, but is limited by the magnetic saturation of the iron circuit. Under extreme conditions, namely a fault on one side, owing to the saturation heavy flux leakage would thread the heavily loaded winding and the ampere-turns of the instrument would become largely unbalanced; consequently a large reactive e.m.f. would be created to oppose the impressed e.m.f. and the particular winding would become in effect a reactance coil in series with the fault current. From the above it appears that there must be a continuous variation of busbar voltage owing to the unbalancing of the particular type of reactor; consequently I am tempted to believe that the Berlin consumers are very much more easily satisfied in respect of the efficiency of their electricity supply than are consumers on this side of the Channel. I have detailed the action of the German reactor since I am aware that we have a fully compensated reactor of British manufacture which can fulfil exactly the same requirements without having the serious disadvantage of interfering with the busbar voltage, except when it is called upon to deal with a fault condition.

The Berlin supply engineers appear to favour a liberal use of the principle of introducing large reactance e.m.f.'s into their fault-rupture problems, in preference to the British method of installing heavy-duty switchgear. It appears to me that sooner or later the limit of size of switchgear will be reached, and we shall have to revert to the method of suppressing the active energy in the ruptured circuit.

THE AUTHOR'S REPLY TO THE DISCUSSIONS AT GLOUCESTER AND PLYMOUTH

Mr. M. W. Humphrey Davies (*in reply*): Mr. Parker will realize that the economic limit for the cost of a Ruths accumulator plant depends largely on local conditions. I am assured that the installation in Berlin has fully justified itself and that the charges for operation and maintenance are within the estimated limits. In an undertaking as large as the Bewag some sort of subdivision of the management was desirable, and the creation of separate technical and commercial sections has proved very satisfactory. The power sales department has several district offices that deal with domestic supplies and with supplies to small workshops. Special attention is paid to the development of domestic sales, and there is a department for testing domestic appliances to ensure that they comply with the specifications of the Verbandes Deutscher Elektrotechniker. This department has done much to encourage the production of sound equipment.

Both Mr. McQueen and Mr. Driscoll refer to the oil-less switchgear that is rapidly replacing the oil-immersed circuit breaker in Germany. These switches have been developed with the object of eliminating oil, and the attendant risk of fire, from switch-houses. Although they are not manufactured in an ironclad form, they can be enclosed in steel cubicles without difficulty. These switches are being made by a number of firms; though they differ considerably in detail, they can all be divided into two classes, the expansion switch and the air-blast switch. A typical expansion switch is shown in Fig. A; up to 60 kV the extinguishing medium is a mixture of glycerine and water, but at higher voltages a small quantity of oil is used. A very small quantity of the fluid is required; the arc is extinguished by the rush of vapour that it generates. Fig. B shows an air-blast switch in which compressed air, at 100 to 150 lb. per sq. in., is used to blow out the arc. Both types of switch are sometimes backed by isolating contacts with an air-break; these are interlinked with the main contacts.

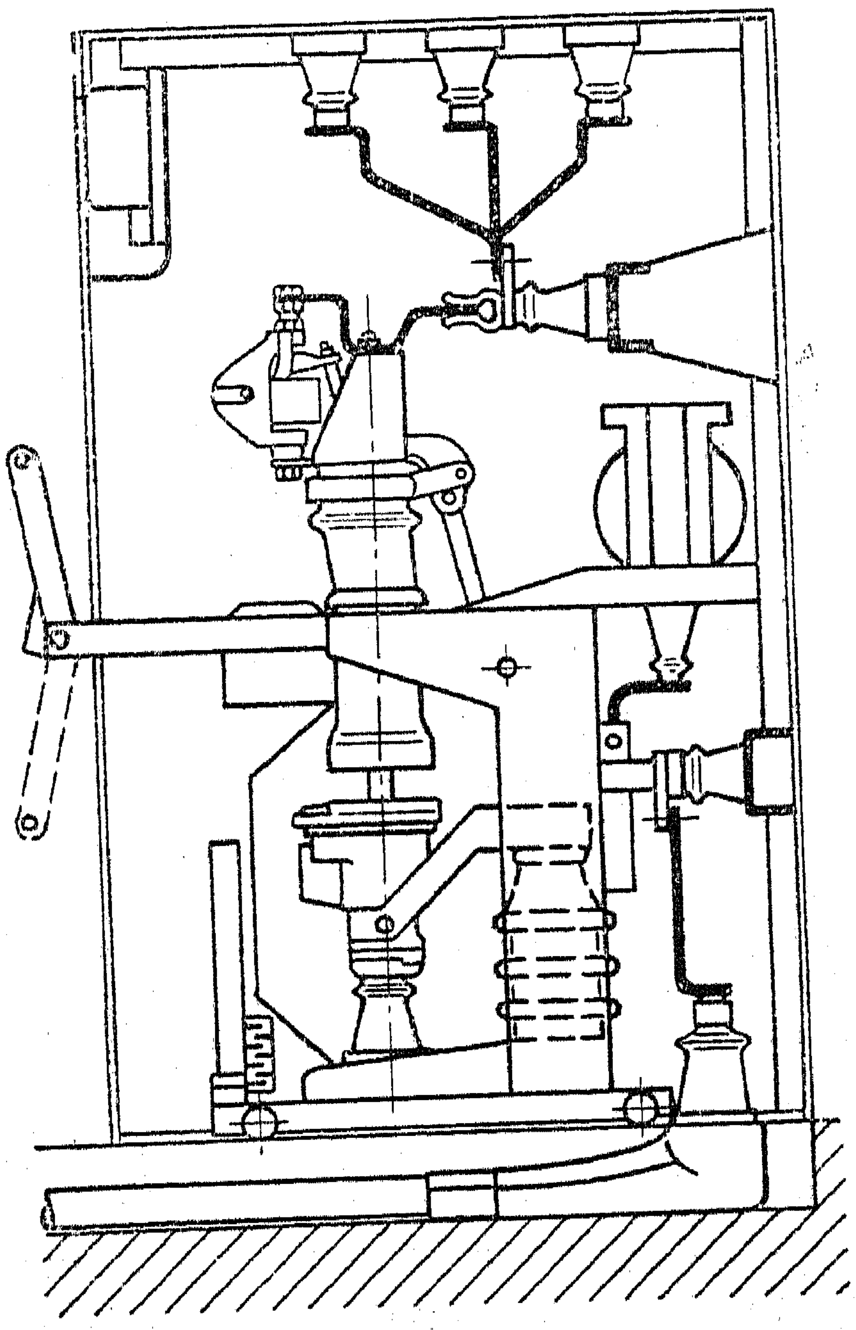

Fig. A.—A typical 10-kV expansion switch enclosed in a steel cubicle. Rupturing capacity 100 000 kVA.

A detailed description of the working of the West Station was given some years ago in the *Elektrotechnische*

Zeitschrift.[*] The thermal efficiency of this station is about 19·5 % at a load factor of 24·5 %. In the year 1934–35, the mean thermal efficiency of the whole system was 22 %. Details of the domestic tariffs were given in my reply to the London discussion:[†] special contracts are made for bulk supplies. The charge for steam depends on the number of calories supplied; these are metered by measuring the volume of condensate and assuming an average heat content for the steam. An allowance is made for the heat remaining in the condensate. Hot water is supplied for space heating at a fixed annual charge per unit area of floor space, and for preparing hot water at a charge based on the volume of water heated and the maximum possible temperature. All steam charges include a coal clause.

Mr. Beckingsale will find an account of the Berlin control-room in Dr. Schleicher's paper.[‡] The room contains instruments for recording the loads on each of the power stations, the imported power, and the demands of one or two large consumers. In addition, certain steam pressures and temperatures can be obtained, and there are relays for indicating the nature and location of disturbances in the system. The company's own pilot cables are used for the communication circuits. The current-limiting reactors are, as Mr. Biles suggests, essential for correct discrimination by the impedance relays. Where there are reactors, the relays are quite satisfactory, even on short cables; in a few cases, where there are no reactors, other systems, e.g. Merz-Price protection, have been used.

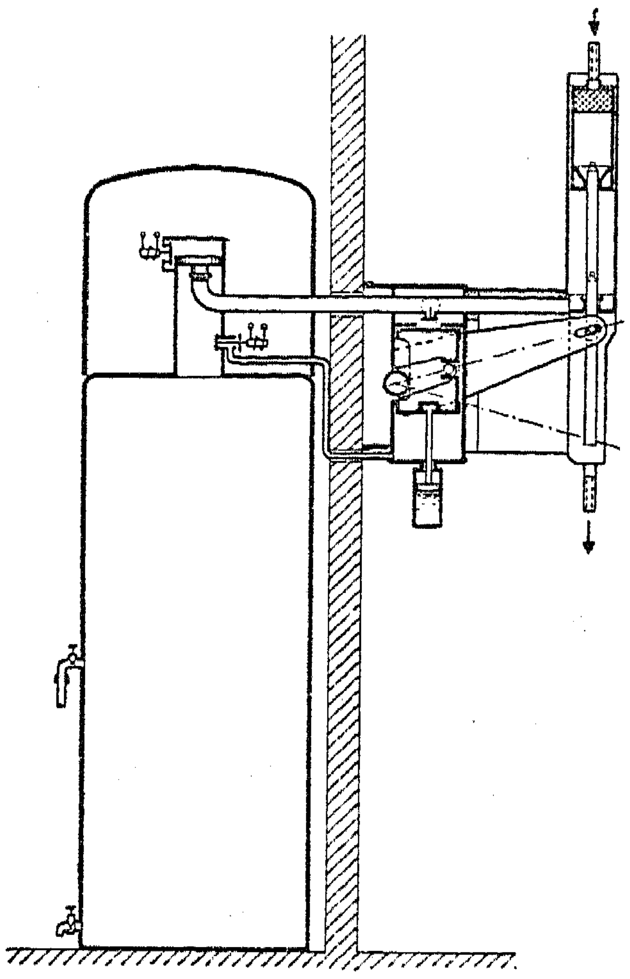

Fig. B.—A compressed-air switch. Switches of this type have been constructed for voltages up to 33 kV, with rupturing capacities of from 100 000 to 400 000 kVA.

The correct setting of the tappings on the Petersen coils in the 30-kV network is controlled by a "compensometer"; this is an instrument for measuring the susceptance to earth of the system neutral, which should be zero for correct compensation.[§] The main reason for introducing these coils was to limit the earth-fault current so that single-phase earth faults, which are the commonest faults on e.h.t. cables, could be cleared before they became short-circuits; this has reduced the number of heavy faults that have to be cleared. The 30-kV cables are all of the 3-core type and the sheaths are adequately bonded through the joints. I am assured that there has never been any trouble from sparking such as Mr. Biles mentions. The network of pilot cables is used mainly for the telephone system, remote measurements, and signals—particularly those for indicating the location of faults in the distribution system. There is very little pilot protection, because other systems, mainly impedance protection, are said to have proved more satisfactory.

In reply to Mr. Hill, there have been no practical difficulties in constructing and operating the self-clearing solid grids for 220 and 380 volts, because all the cables in Berlin are laid in the ground and covered with close-fitting clay tiles. Under these conditions, currents as high as 18 000 amperes can be cleared without difficulty. In the American systems the voltage is lower, usually 110 volts; consequently the arc is more easily extinguished and similar currents can be cleared when the cables are laid in ducts or even in air. The differential choke I have mentioned is only suitable for low-voltage *grids.* It consists of two closely-coupled coils with an air core and no iron; half the outgoing feeders are connected to each coil. Under normal conditions *in a solid grid* the loads on the two halves will be practically equal, and the ampere-turns of the two halves will cancel out; when a fault occurs, the loading is unbalanced and the current in one half tends to reverse, bringing the full inductance of the coils into action. The Petersen coils have been evenly distributed throughout the 30-kV network in order to avoid the risk of the selective action of the earth-fault protective relays being affected by circulating zero-phase currents; if the coils are unevenly distributed such currents are likely to be produced. In compensated systems, the earth-fault current is small and most of the objections to multiple earthing are removed.

I think Mr. Hocking will find that the arrangements for maintaining continuity of supply in Berlin are as good as any in this country. In the unattended 6-kV substations a reserve cable is automatically brought into service when one of the main 6-kV feeders fails. The tripping of one of the 6-kV ring-mains or a transformer box is automatically signalled to one of the breakdown gangs. The complete failure of one of these rings is scarcely noticeable in the "gridded" networks. A dead low-voltage network is not energized by closing the switches in the transformer boxes, but by closing one or two switches in the main substation supplying the network. During the 6 or 7 years they have been in existence, there have been no serious disturbances in the low-voltage grids.

In reply to Mr. Crocker's questions, ordinary impregnated-paper cables with lead sheaths are used for the low-voltage grids; special cables have not been employed. There have been no street explosions, and standard main fuses with an air break are used on consumers' premises. The growth of the load is allowed for in planning the network; the reserve transformer capacity

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[*] *Elektrotechnische Zeitschrift*, 1930, vol. 51, pp. 485, 557.

[†] *Journal I.E.E.*, 1937, vol. 80, p. 325.

[‡] *Ibid.*, 1934, vol. 75, p. 717.

[§] E. SCHULZE: "Earth-Fault Problems on Large Cable Systems," *Elektrizitätswirtschaft*, 1933, vol. 32, pp. 277, 298.

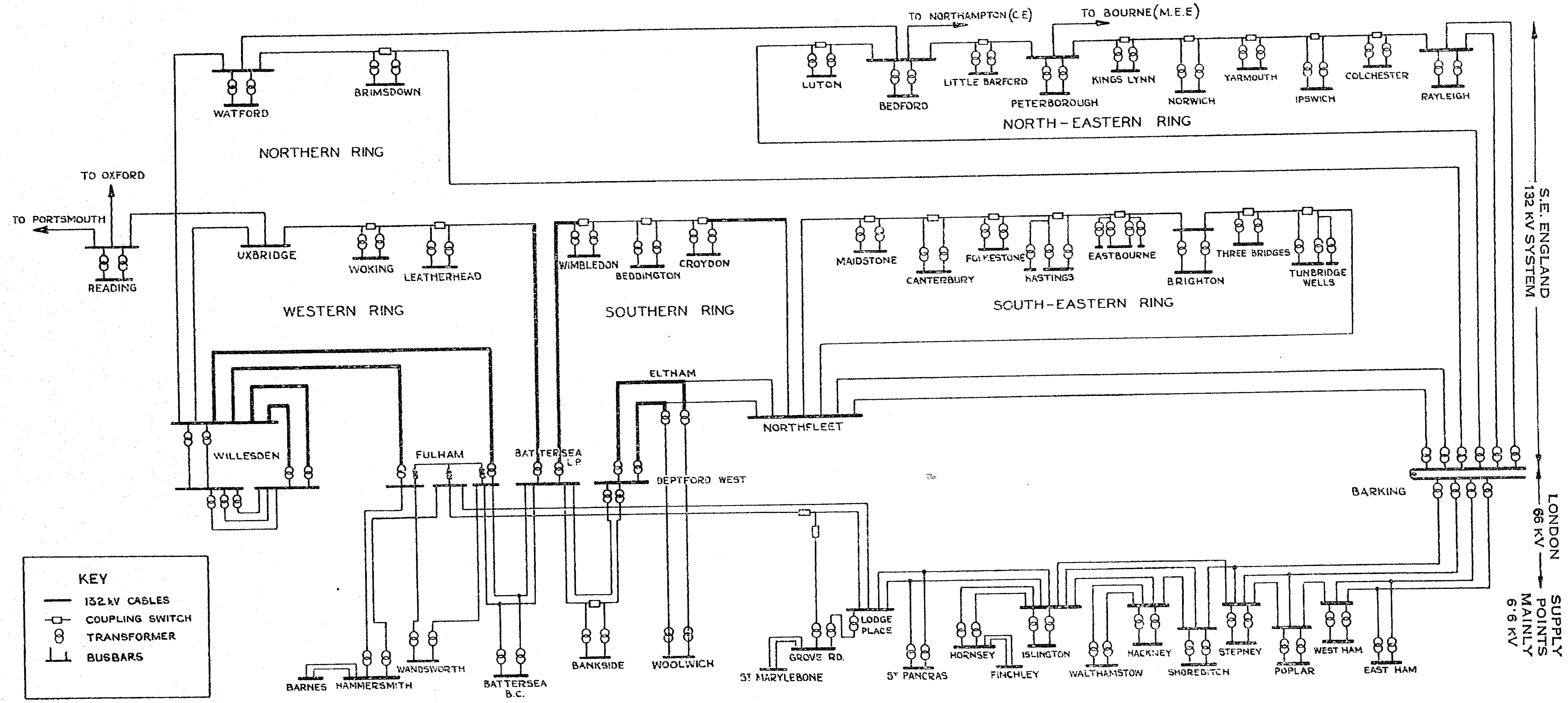

Fig. C.—Diagram of the South-East England grid, including the London cable system (66 kV), showing how the smaller generating stations are comparable with "distributing stations."

is required to prevent overloading if an h.t. feeder or a transformer should fail. Mr. Midgley is correct in supposing that there are no vulcanized-bitumen cables in the low-voltage grids. All cables are laid in the ground and covered with close-fitting tiles that are shaped to fit the cables. Ducts are only used at important crossings, as there is a tendency for the burning to continue. Faults are detected by a continuity test; they are located by one of the usual methods. Repairs are usually carried out with the cable dead; if it *must* be alive, fuses can be inserted. The 30-kV cables were introduced many years ago for the sake of economy; the congestion under the streets was not considered. There is no appreciable difference in the time of action of compressed-air-operated and solenoid-operated switches. The pipe-runs are not complicated, as the valves are controlled electrically.

The 30-kV cables in Berlin are only a few miles long, but the current-limiting reactors increase the impedance sufficiently to make impedance protection entirely satisfactory. As stated in the paper, the differential chokes for the low-voltage grids are air-cored, not iron-cored; there is therefore no saturation effect. Their operation is described in my reply to Mr. Hill. In a grid the two loads are so nearly equal that the bucking, to which Mr. Mackay refers, does not arise. The choke he describes would, of course, be preferable on a radial system. The limiting short-circuit kVA in a distribution system is mainly a matter of economics, but that is a question I must leave to those who have had more experience.

In order to illustrate my remarks in reply to Mr. Marshall in the London discussion (vol. 80, page 322), I reproduce in Fig. C a diagram of the South-Eastern grid.

INSTITUTION NOTES

OVERSEAS MEMBERS AND THE INSTITUTION

During the period 1st July to 30th September, 1937, the following members from overseas called at The Institution and signed the "Attendance Register of Overseas Members":—

Attard, A. (*Malta*).
Barker, H. G. (*Khartoum*).
Bayliss, W. C. (*Melbourne*).
Beck, R., Dipl.Ing. (*Budapest*).
Brasher, W. K., B.A. (*Jerusalem*).
Coninck-Westenberg, D. J. L. (*Ginneken, Holland*).
Cousins, C. G., B.Sc.(Eng.) (*Rosario*).
Cresswell, F. G. (*Melbourne*).
Critchley, V. F. (*Lahore*).
de Moura, T. C. C., B.Sc.(Eng.) (*Lisbon*).
de Necker, J. D. J. (*Colenso*).
Ewer, Lieut. Col. G. G., D.S.O., T.D. (*Pietermaritzburg*).
Fuad, I. (*Cairo*).
Gardner, V. A. (*Rangoon*).
Habberjam, J. (*Taiping, F.M.S.*).
Jordan, F. V. (*Baghdad*).
Maloney, J. (*St. Vincent*).
Martin, R. H. (*Trichinopoly*).
Morris, R. P. (*Hong Kong*).
Norfolk, H. L. (*Bombay*).
North, B., B.Eng. (*Calcutta*).
Ogden, Captain G. W., B.A. (*Khartoum*).
Polydoroff, W. J. (*Chicago*).
Rao, K. N. Ranga, B.E. (*Calcutta*).
Robertson, J. R. F., B.Sc. (*Gold Coast*).
Sexton, C. E. (*Bombay*).
Somersgale, C. W. (*Montevideo*).
Ward, L. G. W., B.Sc.(Eng.) (*Selangor, F.M.S.*).
Wells, R. H. (*Jerusalem*).
Wright, H. C. (*Abadan*).

SCHOLARSHIPS

The following Scholarships have been awarded for 1937 by the Council:—

Duddell Scholarship (*Annual Value* £150; *tenable for* 3 *years*).

R. S. Peacock (King's School, Ely).

Swan Memorial Scholarship (*Value* £120; *tenable for* 1 *year*).

B. C. Robinson, Ph.D. (Armstrong College, Newcastle-on-Tyne).

William Beedie Esson Scholarship (*Annual Value* £120; *tenable for* 2 *years, renewable in approved cases for a third year*).

R. P. Kinsey (Evershed and Vignoles, Ltd.).

Silvanus Thompson Scholarship (*Annual Value* £100, *plus tuition fees*; *tenable for* 2 *years*).

J. R. Catlin (Igranic Co., Ltd.).

David Hughes Scholarship (*Value* £100; *tenable for* 1 *year*).

L. Lieberman (Queen Mary College, London).

Salomons Scholarship (*Value* £100; *tenable for* 1 *year*).

S. G. Bittles (College of Technology, Belfast).

Paul Scholarship (*Annual Value* £50; *tenable for* 2 *years*).

F. L. Johnson (Holloway School, London).

Thorrowgood Scholarships (*Annual Value* £12 10*s. each*; *tenable for* 2 *years*).

J. S. Davis (London, Midland, and Scottish Railway Co.).

W. P. Hill (London Passenger Transport Board).

WAR THANKSGIVING EDUCATION AND RESEARCH FUND (No. 1)

A grant of £50 has been made for 1937–1938 to J. E. Parton, B.Sc. (Birmingham University) for research purposes.

PROCEEDINGS OF THE WIRELESS SECTION

134TH MEETING OF THE WIRELESS SECTION, 3RD FEBRUARY, 1937

Dr. E. Mallett, Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 6th January, 1937, were taken as read and were confirmed and signed.

A discussion, opened by Mr. Stuart Hill, took place on "R.M.A. Specification for Testing and Expressing the Overall Performance of Radio Receivers" (see page 104).

A vote of thanks to Mr. Hill for his opening remarks was moved by the Chairman and carried with acclamation.

135TH MEETING OF THE WIRELESS SECTION, 3RD MARCH, 1937

Dr. E. Mallett, Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 3rd February, 1937, were taken as read and were confirmed and signed.

A paper by Commander F. G. Loring, O.B.E., R.N., Member, and Messrs. W. L. McPherson, B.Sc.(Eng.), Associate Member, and W. H. McAllister, Associate Member, entitled "A Survey of Marine Radio Progress, with special reference to R.M.S. 'Queen Mary'" (see page 183), was read and discussed.

A vote of thanks to the authors, moved by the Chairman, was carried with acclamation.

10TH INFORMAL MEETING OF THE WIRELESS SECTION, 23RD MARCH, 1937

Dr. E. Mallett, Chairman of the Section, took the chair at 6.30 p.m.

The minutes of the Informal Meeting held on the 26th January, 1937, were taken as read and were confirmed and signed.

A discussion, opened by Mr. R. G. Parry, took place on "Radio Reception in Automobiles."

At the conclusion of the discussion a vote of thanks was accorded to Mr. Parry for his introductory remarks.

136TH MEETING OF THE WIRELESS SECTION, 7TH APRIL, 1937

Dr. E. Mallett, Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 3rd March, 1937, were taken as read and were confirmed and signed.

The Chairman then called upon Dr. B. Van der Pol to deliver his lecture on "Discontinuous Phenomena in Radio Communication" (see page 381).

A vote of thanks to the lecturer, proposed by Dr. W. H. Eccles, F.R.S., and seconded by Mr. R. A. Watson Watt, B.Sc.(Eng.), was carried with acclamation.

137TH MEETING OF THE WIRELESS SECTION, 5TH MAY, 1937

Dr. E. Mallett, Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 7th April, 1937, were taken as read and were confirmed and signed.

The Chairman announced that the following members had been nominated to fill the vacancies which would occur on the Committee on the 30th September, 1937:—

Chairman: T. Wadsworth, M.Sc.

Vice-Chairman: W. J. Picken.

Ordinary Members of Committee: R. P. G. Denman, B.A., T. E. Goldup, H. L. Kirke, and E. B. Moullin, M.A.

In the event of a ballot for the new Committee being required, Colonel C. J. Aston and Mr. W. H. Nottage were appointed scrutineers.

A paper by Mr. L. B. Turner, M.A., Member, entitled "Constant Temperature: A Study of Principles in Electric Thermostat Design; and a Mains-Operated Isothermal Chamber Constant to One-Thousandth of a Degree Centigrade" (see page 399), was read and discussed. Prior to the discussion the author's apparatus was shown in operation and various demonstrations were made.

A vote of thanks to the author, moved by the Chairman, was carried with acclamation.

PROCEEDINGS OF THE METER AND INSTRUMENT SECTION

66TH MEETING OF THE METER AND INSTRUMENT SECTION, 12TH FEBRUARY, 1937

Mr. G. F. Shotter, Chairman of the Section, took the chair at 7 p.m.

The minutes of the meeting held on the 8th January, 1937, were taken as read and were confirmed and signed.

A paper by Messrs. B. G. Churcher, Member, and A. J. King, B.Sc.Tech., Associate Member, entitled "The Performance of Noise Meters in Terms of the Primary Standard" (see page 57), was read and discussed.

A vote of thanks to the authors, moved by the Chairman, was carried with acclamation.

67TH MEETING OF THE METER AND INSTRUMENT SECTION, 5TH MARCH, 1937

Mr. G. F. Shotter, Chairman of the Section, took the chair at 7 p.m.

The minutes of the meeting held on the 12th February, 1937, were taken as read and were confirmed and signed.

A paper by Mr. C. Dannatt, D.Sc., Member, entitled "The Metering of Mercury-Arc Rectifier Supplies and Outputs" (see page 256), was read and discussed.

A vote of thanks to the author, moved by the Chairman, was carried with acclamation.

68TH MEETING OF THE METER AND INSTRUMENT SECTION, 19TH MARCH, 1937

Mr. G. F. Shotter, Chairman of the Section, took the chair at 7 p.m.

The minutes of the meeting held on the 5th March, 1937, were taken as read and were confirmed and signed.

A discussion, opened by Mr. E. E. Sharp, took place on "Metering Conditions in the U.S.A. and Canada." At the conclusion of the discussion a vote of thanks was accorded to Mr. Sharp for his introductory remarks.

69TH MEETING OF THE METER AND INSTRUMENT SECTION, 2ND APRIL, 1937

Mr. G. F. Shotter, Chairman of the Section, took the chair at 7 p.m.

The minutes of the meeting held on the 19th March, 1937, were taken as read and were confirmed and signed.

A paper by Messrs. J. Prince, Associate Member, and M. Whitehead, Graduate, entitled "Coin Mechanisms, with particular reference to Electricity Meters" (see page 515), was read and discussed.

A vote of thanks to the authors, moved by the Chairman, was carried with acclamation.

70TH MEETING OF THE METER AND INSTRUMENT SECTION, 16TH APRIL, 1937

Mr. G. F. Shotter, Chairman of the Section, took the chair at 7 p.m.

The minutes of the meeting held on the 2nd April, 1937, were taken as read and were confirmed and signed.

The Chairman then called upon Mr. J. B. Kramer, Member, to deliver his Lecture on "The Photocell and its Application in Industry," which was followed by an informal discussion.

A vote of thanks to the lecturer, moved by the Chairman, was carried with acclamation.

71ST MEETING OF THE METER AND INSTRUMENT SECTION, 7TH MAY, 1937

Mr. G. F. Shotter, Chairman of the Section, took the chair at 7 p.m.

The minutes of the meeting held on the 16th April, 1937, were taken as read and were confirmed and signed.

The Chairman announced that the following members had been nominated to fill the vacancies which would occur on the Committee on the 30th September, 1937:—

Chairman: H. Cobden Turner.

Vice-Chairman: B. S. Cohen, O.B.E.

Ordinary Members of Committee: A. Felton, B.Sc.(Eng.), E. Grundy, B.Sc.Tech., and A. E. Quenzer.

In the event of a ballot for the new Committee being required, Messrs. F. O. Barralet and L. J. Matthews were appointed scrutineers.

The Chairman then called upon Sir Frank E. Smith, K.C.B., C.B.E., D.Sc., LL.D., to deliver his lecture on "Fundamental Electrical Measurements." The lecture was accompanied by demonstrations.

A vote of thanks to the lecturer, moved by Prof. J. T. MacGregor-Morris and seconded by Mr. F. C. Knowles, was carried with acclamation.

PROCEEDINGS OF THE TRANSMISSION SECTION

17TH MEETING OF THE TRANSMISSION SECTION, 13TH JANUARY, 1937

Dr. P. Dunsheath, O.B.E., M.A., Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 9th December, 1936, were taken as read and were confirmed and signed.

A paper by Mr. J. Eccles, B.Sc., Associate Member, entitled "The Efficient Rating and Disposition of Supply Apparatus on High-Voltage Systems" (see page 229), was read and discussed.

A vote of thanks to the author, moved by the Chairman, was carried with acclamation.

18TH MEETING OF THE TRANSMISSION SECTION, 10TH FEBRUARY, 1937

Dr. P. Dunsheath, O.B.E., M.A., Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 13th January, 1937, were taken as read and were confirmed and signed.

A paper by Mr. J. D. Peattie, Associate Member, entitled "Control Rooms and Control Equipment of the Grid System," was read and discussed.

A vote of thanks to the author, moved by the Chairman, was carried with acclamation.

19TH MEETING OF THE TRANSMISSION SECTION, 10TH MARCH, 1937

Dr. P. Dunsheath, O.B.E., M.A., Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 10th February, 1937, were taken as read and were confirmed and signed.

A paper by Mr. A. N. Arman, B.Sc.(Eng.), Associate Member, entitled "The Gas-Impregnated Cable," was read and discussed.

A vote of thanks to the author, moved by the Chairman, was carried with acclamation.

20TH MEETING OF THE TRANSMISSION SECTION, 14TH APRIL, 1937

Dr. P. Dunsheath, O.B.E., M.A., Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 10th March, 1937, were taken as read and were confirmed and signed.

A paper by Mr. H. G. Taylor, M.Sc.(Eng.), Associate Member, entitled "The Use of Protective Multiple Earthing and Earth-Leakage Circuit Breakers in Rural Areas," was read and discussed.

A vote of thanks to the author, moved by the Chairman, was carried with acclamation.

21ST MEETING OF THE TRANSMISSION SECTION, 29TH APRIL, 1937

Dr. P. Dunsheath, O.B.E., M.A., Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 14th April, 1937, were taken as read and were confirmed and signed.

The Chairman announced that the following members had been nominated to fill the vacancies which would occur on the Committee on the 30th September, 1937:—

Chairman : J. L. Eve.

Vice-Chairman : S. R. Siviour.

Ordinary Members of Committee : N. K. Bunn, N. Cresswell, P. K. Davis, W. J. John, and C. R. Westlake.

In the event of a ballot for the new Committee being required, Messrs. J. G. Griffin and L. M. Jockel were appointed scrutineers.

Mr. P. M. J. Ailleret then delivered a lecture on "Recent Developments in the Transmission of Electricity in France."

A vote of thanks to the lecturer, moved by the Chairman and seconded by Mr. W. E. Highfield, was carried with acclamation.

STYRENATION

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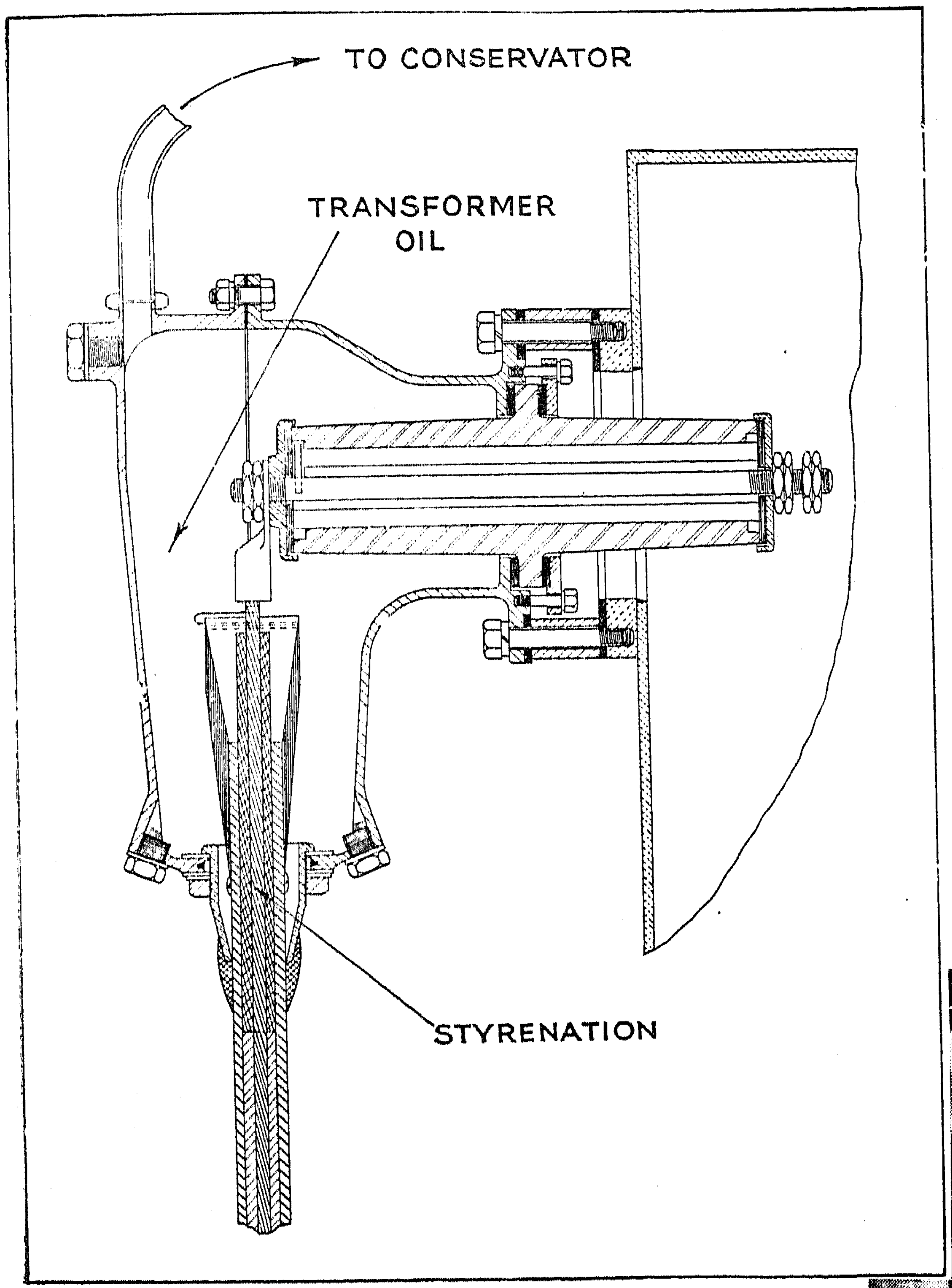

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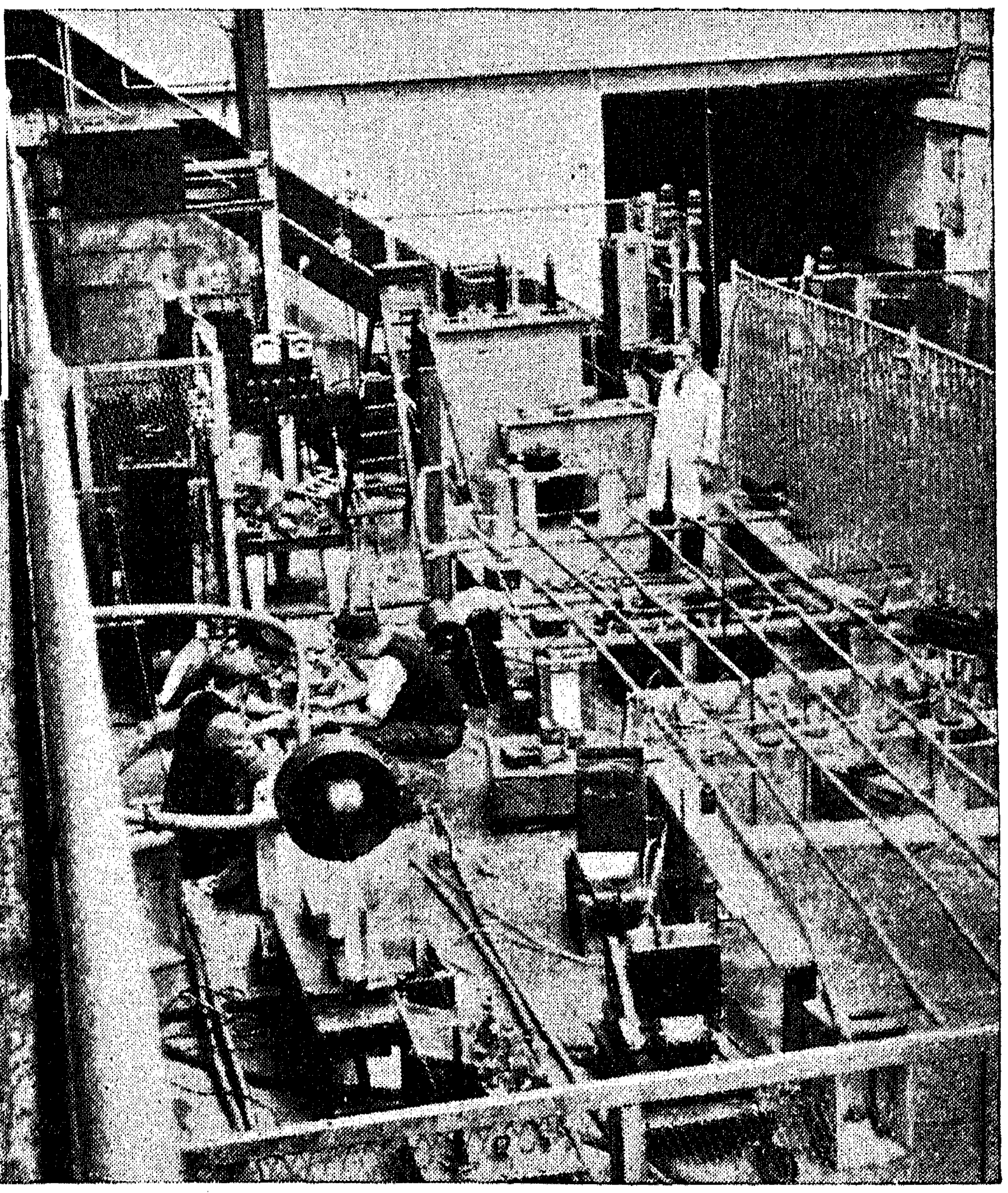

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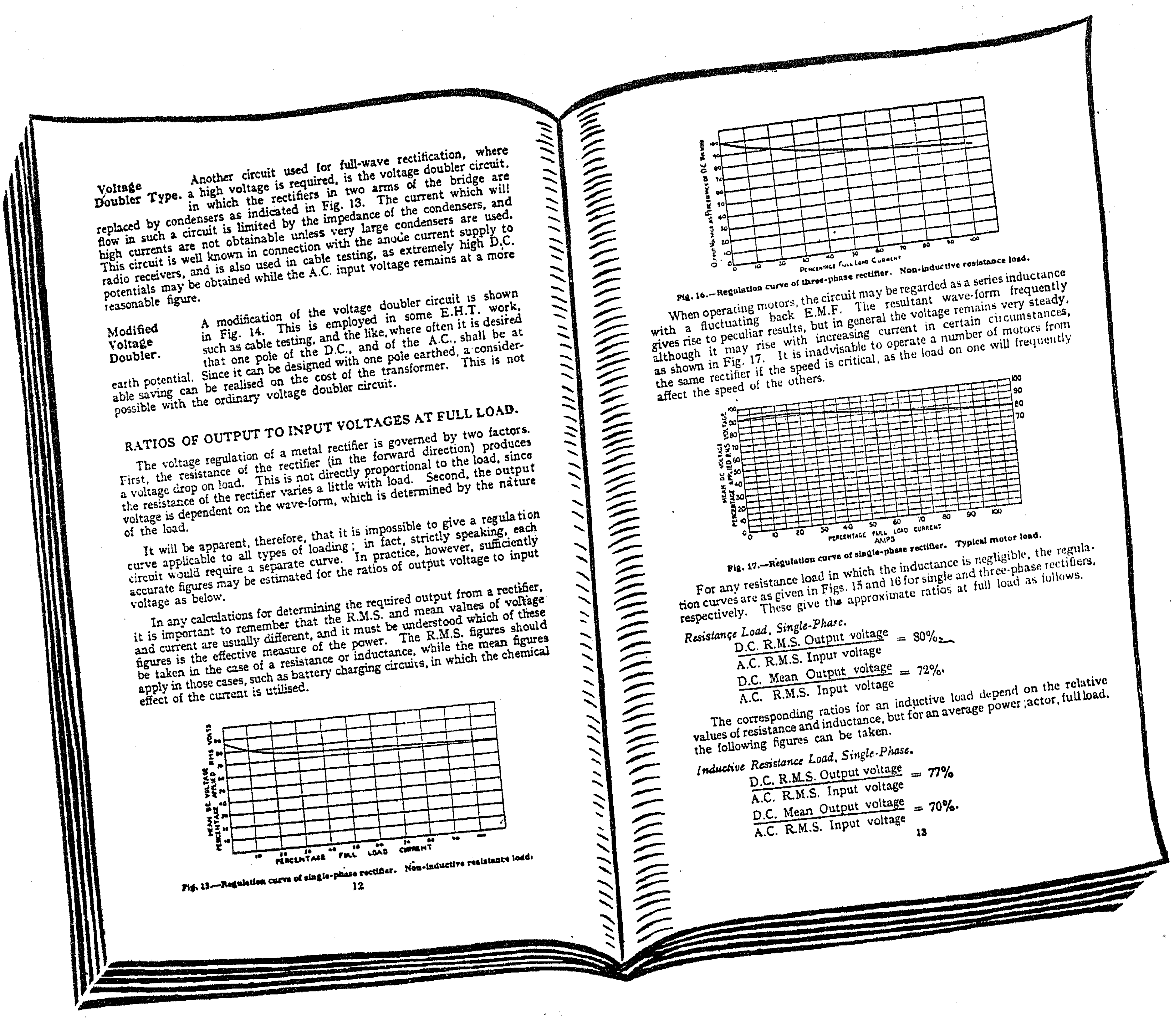

Voltage Doubler Type. Another circuit used for full-wave rectification, where a high voltage is required, is the voltage doubler circuit, in which the rectifiers in two arms of the bridge are replaced by condensers as indicated in Fig. 13. The current which will flow in such a circuit is limited by the impedance of the condensers, and high currents are not obtainable unless very large condensers are used. This circuit is well known in connection with the anode current supply to radio receivers, and is also used in cable testing, as extremely high D.C. potentials may be obtained while the A.C. input voltage remains at a more reasonable figure.

Modified Voltage Doubler. A modification of the voltage doubler circuit is shown in Fig. 14. This is employed in some E.H.T. work, such as cable testing, and the like, where often it is desired that one pole of the D.C., and of the A.C., shall be at earth potential. Since it can be designed with one pole earthed, a considerable saving can be realised on the cost of the transformer. This is not possible with the ordinary voltage doubler circuit.

RATIOS OF OUTPUT TO INPUT VOLTAGES AT FULL LOAD.

The voltage regulation of a metal rectifier is governed by two factors. First, the resistance of the rectifier (in the forward direction) produces a voltage drop on load. This is not directly proportional to the load, since the resistance of the rectifier varies a little with load. Second, the output voltage is dependent on the wave-form, which is determined by the nature of the load.

It will be apparent, therefore, that it is impossible to give a regulation curve applicable to all types of loading; in fact, strictly speaking, each circuit would require a separate curve. In practice, however, sufficiently accurate figures may be estimated for the ratios of output voltage to input voltage as below.

In any calculations for determining the required output from a rectifier, it is important to remember that the R.M.S. and mean values of voltage and current are usually different, and it must be understood which of these figures is the effective measure of the power. The R.M.S. figures should be taken in the case of a resistance or inductance, while the mean figures apply in those cases, such as battery charging circuits, in which the chemical effect of the current is utilised.

MEAN DC VOLTAGE PERCENTAGE APPLIED RMS VOLTS
PERCENTAGE FULL LOAD CURRENT

Fig. 15.—Regulation curve of single-phase rectifier. Non-inductive resistance load.

12

Fig. 16.—Regulation curve of three-phase rectifier. Non-inductive resistance load.

When operating motors, the circuit may be regarded as a series inductance with a fluctuating back E.M.F. The resultant wave-form frequently gives rise to peculiar results, but in general the voltage remains very steady, although it may rise with increasing current in certain circumstances, as shown in Fig. 17. It is inadvisable to operate a number of motors from the same rectifier if the speed is critical, as the load on one will frequently affect the speed of the others.

Fig. 17.—Regulation curve of single-phase rectifier. Typical motor load.

For any resistance load in which the inductance is negligible, the regulation curves are as given in Figs. 15 and 16 for single and three-phase rectifiers, respectively. These give the approximate ratios at full load as follows.

Resistance Load, Single-Phase.

$$\frac{\text{D.C. R.M.S. Output voltage}}{\text{A.C. R.M.S. Input voltage}} = 80\%$$

$$\frac{\text{D.C. Mean Output voltage}}{\text{A.C. R.M.S. Input voltage}} = 72\%.$$

The corresponding ratios for an inductive load depend on the relative values of resistance and inductance, but for an average power factor, full load, the following figures can be taken.

Inductive Resistance Load, Single-Phase.

$$\frac{\text{D.C. R.M.S. Output voltage}}{\text{A.C. R.M.S. Input voltage}} = 77\%$$

$$\frac{\text{D.C. Mean Output voltage}}{\text{A.C. R.M.S. Input voltage}} = 70\%.$$

13

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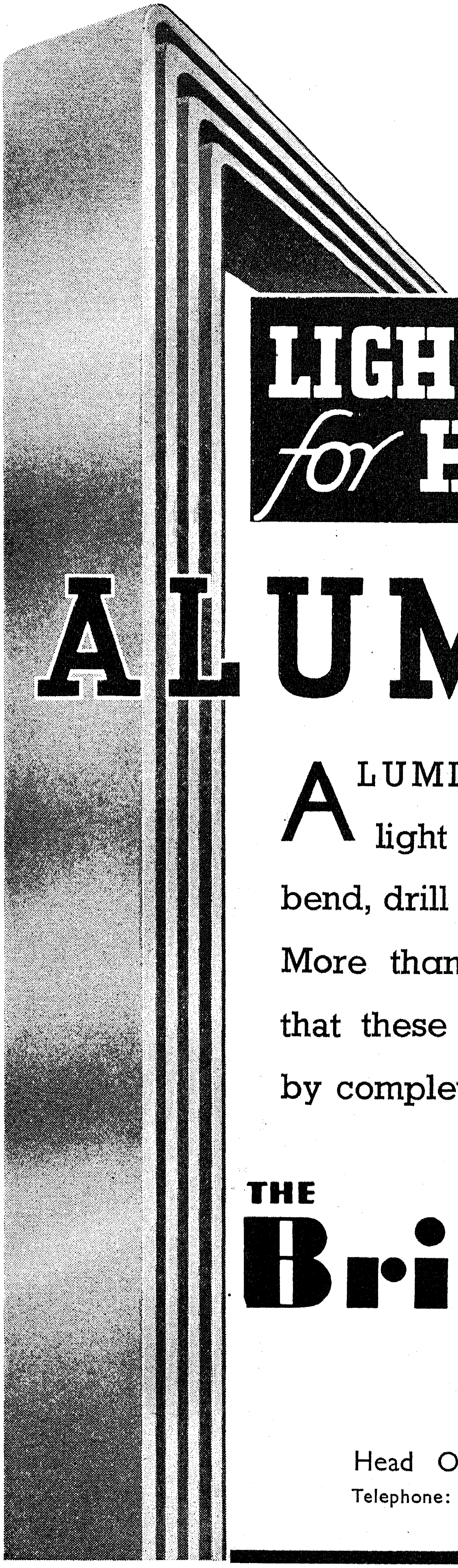

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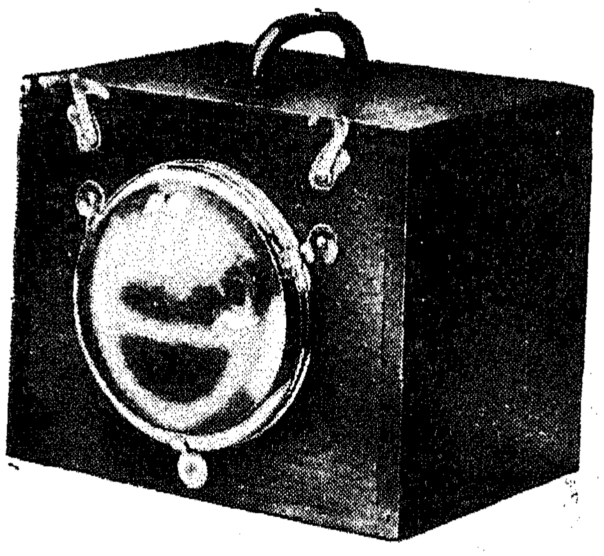

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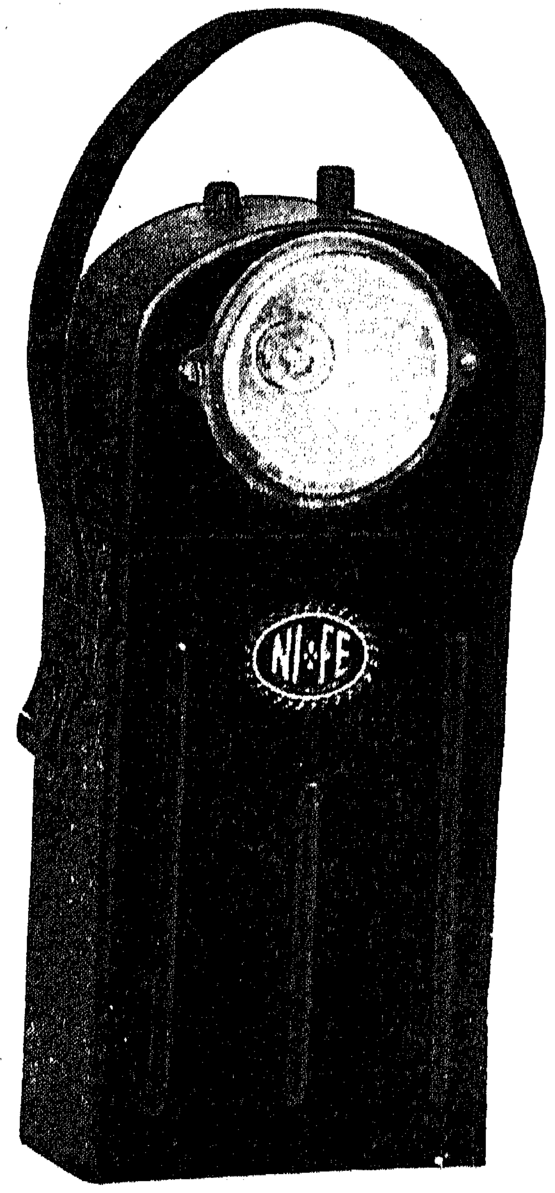

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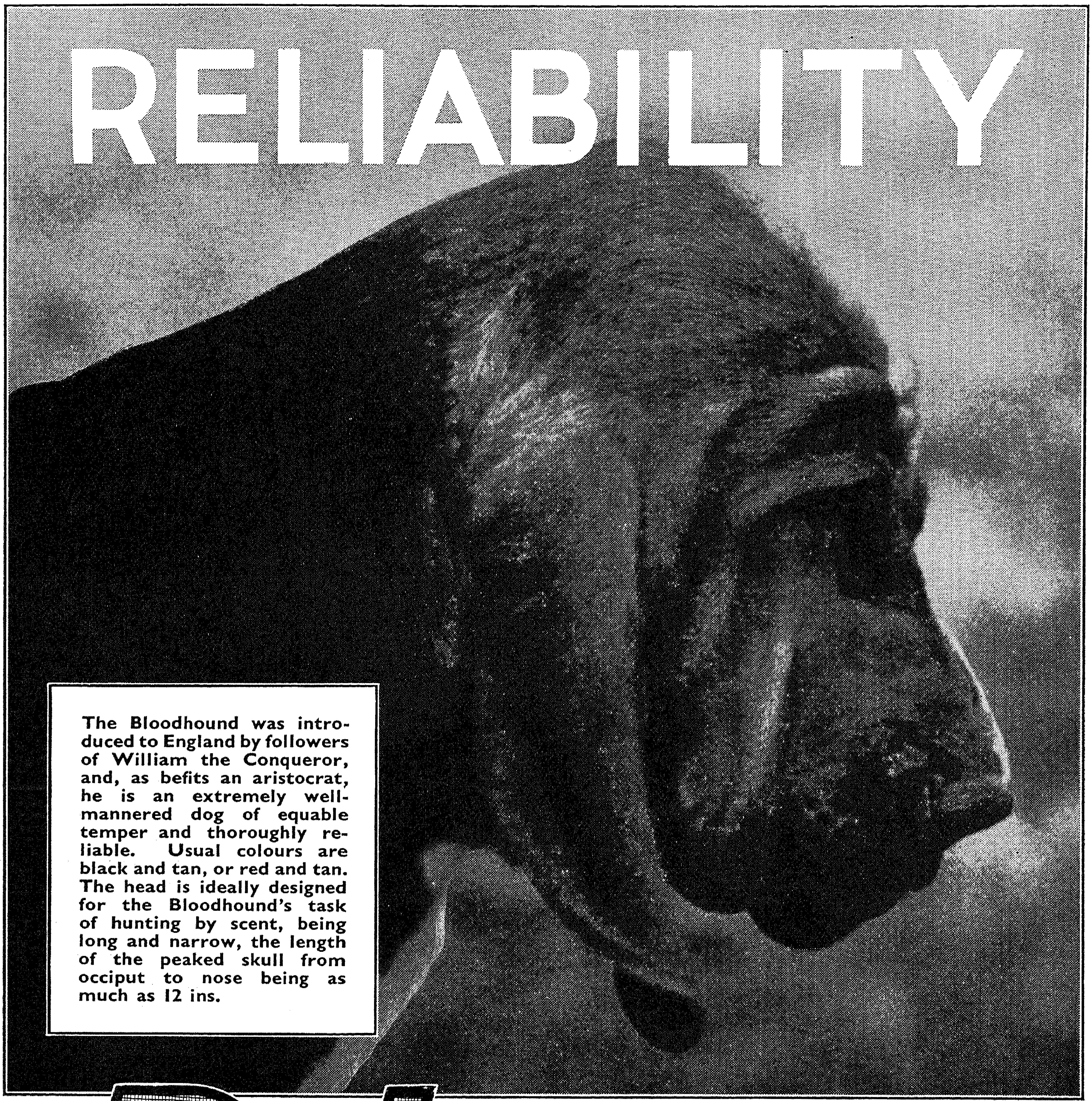

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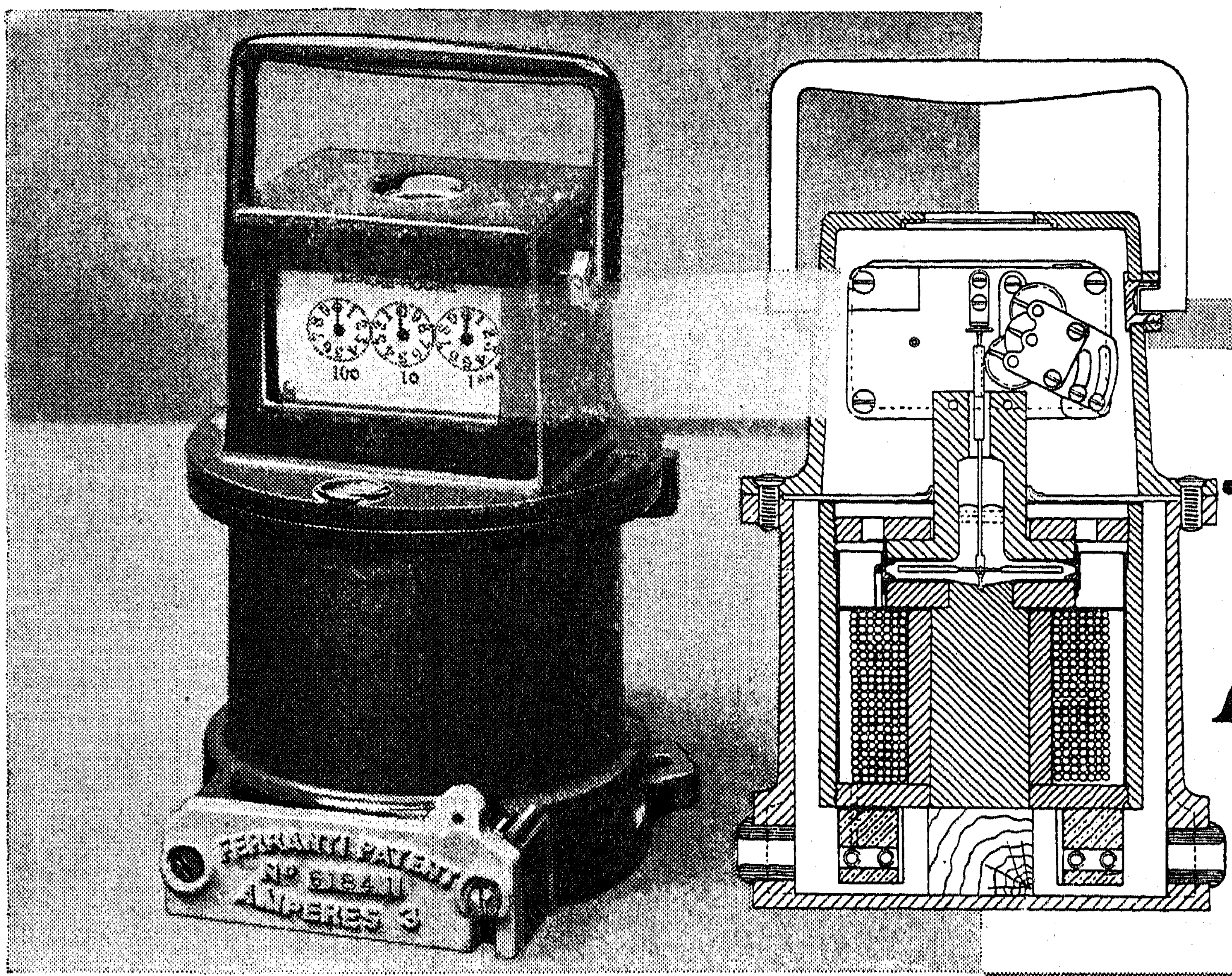
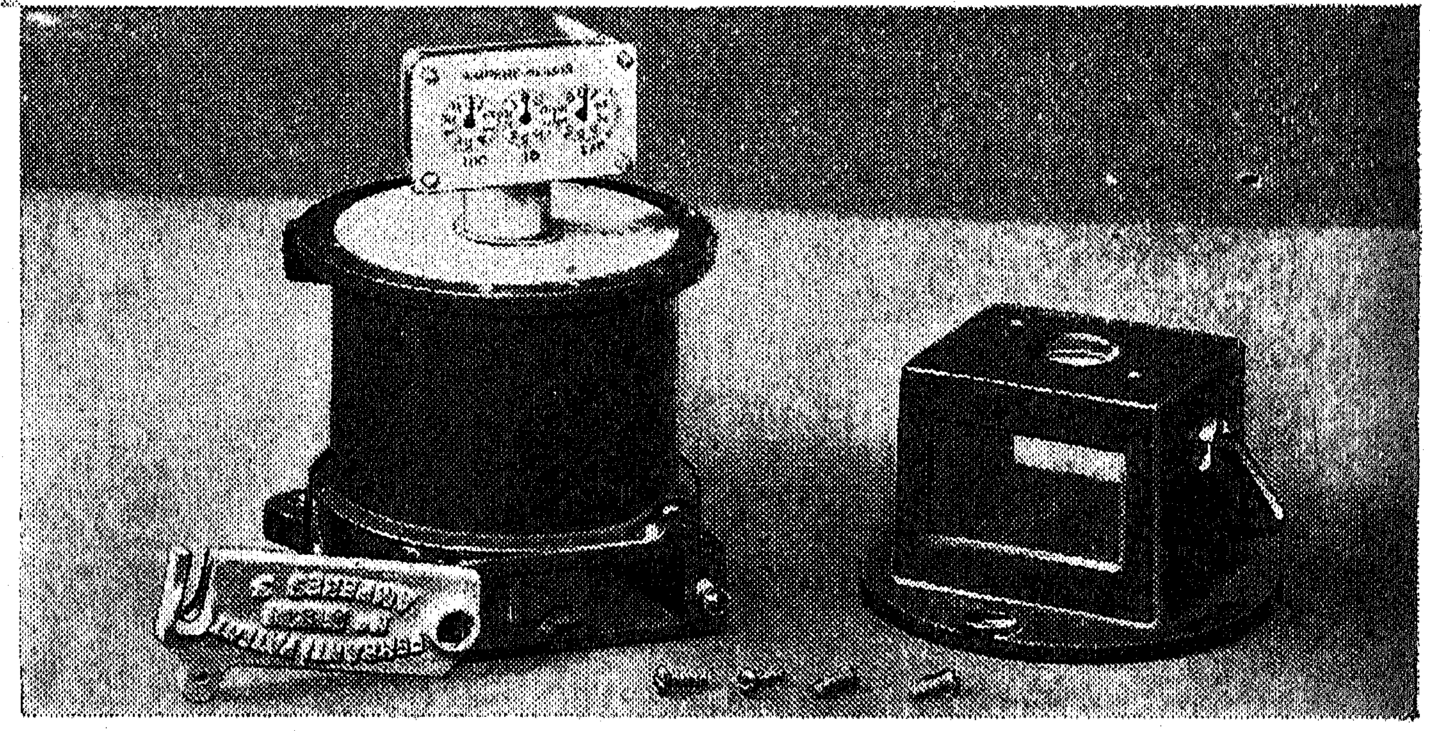


...*Pioneer work by Ferranti in Electric Metering*

No. 4



This continuous current meter was produced in 1895. It is an ampere-hour meter, and differs only in size and constructional detail from the original D.C. meter of 1884. It was the first Ferranti meter with its dial mounted vertically, and provision was made for independent sealing of the meter element and the terminals.

FERRANTI Meters

No. 1 of this series

ANNO DOMINI 1884

....*Pioneer work by Ferranti in Electric Metering* No. 1

FERRANTI METERS

No. 2 of this series

ANNO DOMINI 1885

....*Pioneer work by Ferranti in Electric Metering* No. 2

FERRANTI METERS

No. 3 of this series

ANNO DOMINI 1890

...*Pioneer work by Ferranti in Electric Metering* No. 3

FERRANTI METERS

This meter was described in an address given by Dr. Ferranti before the Royal Scottish Society of Arts at Edinburgh, on January 4th, 1895, and appears in the Transactions of the Royal Scottish Society of Arts, Vol. 14, pages 52-65, 1898.

FM62

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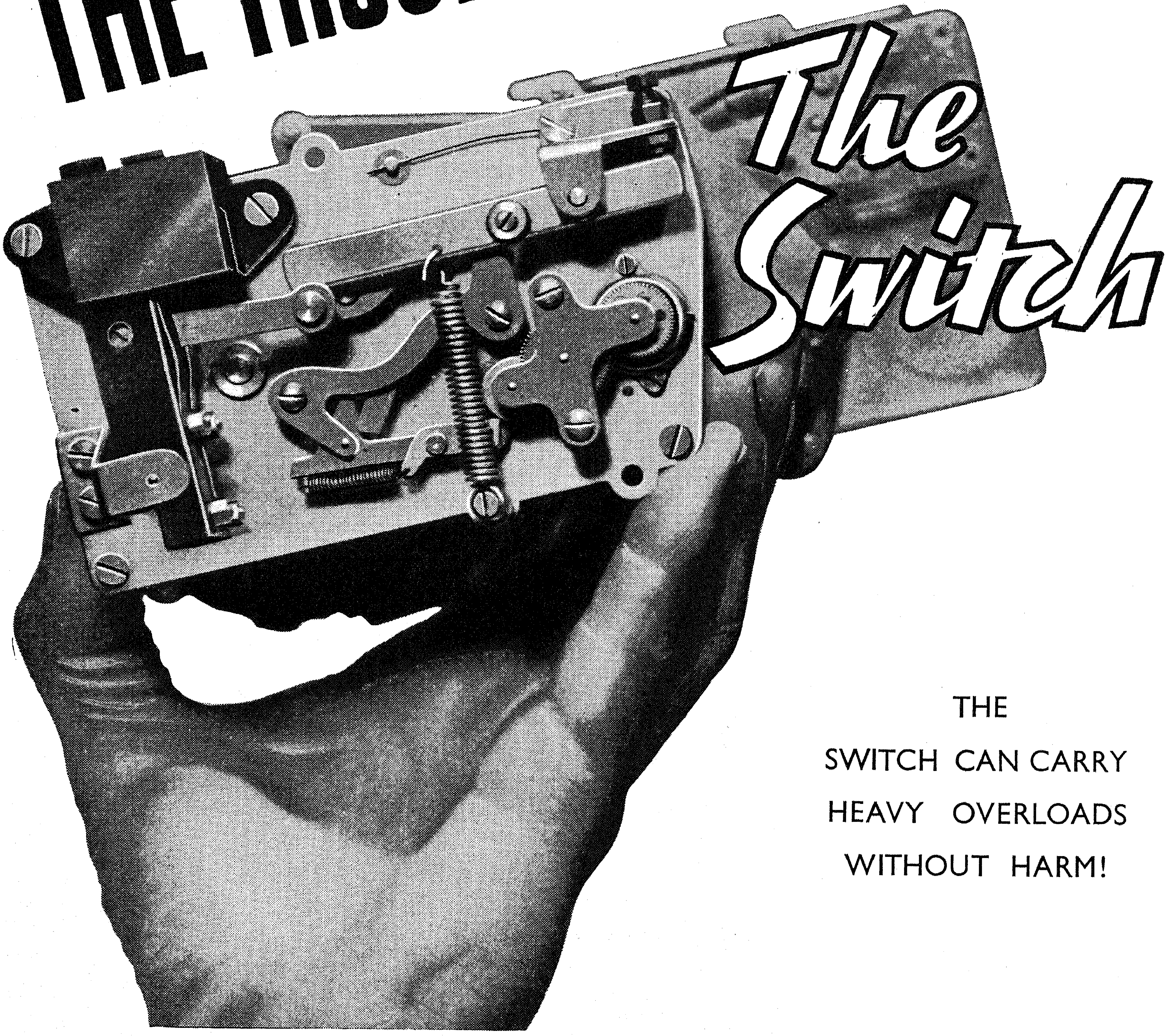

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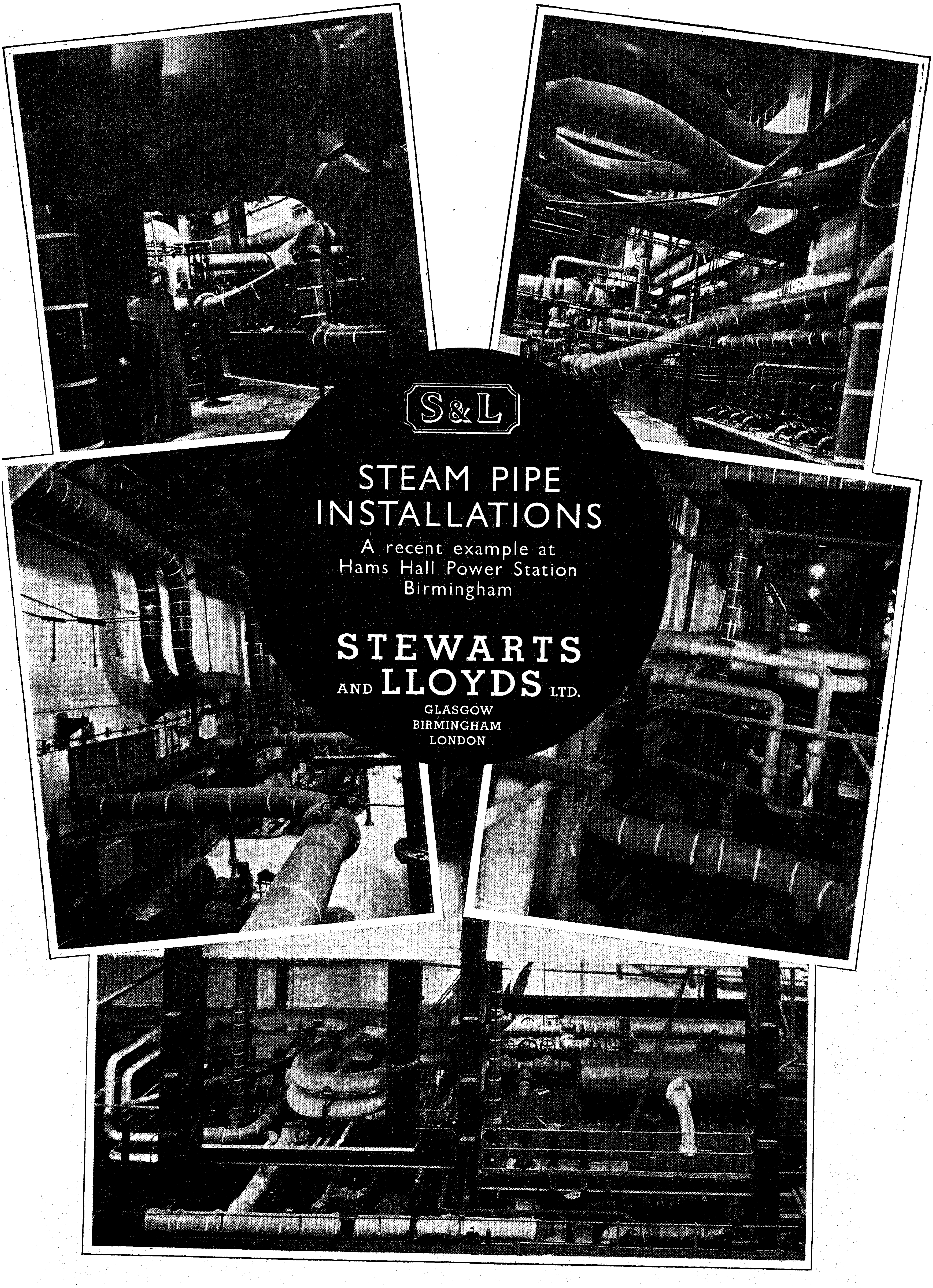

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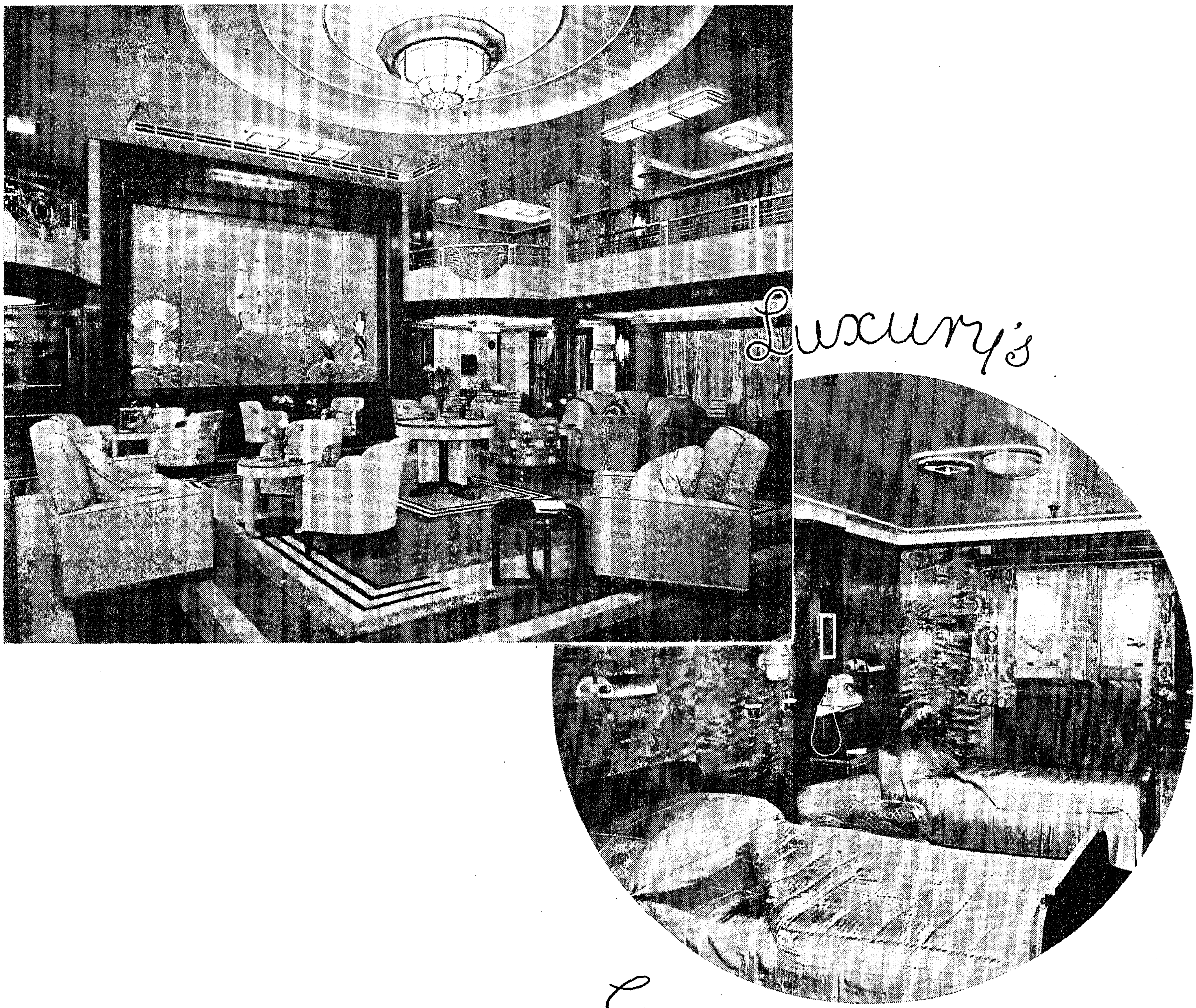

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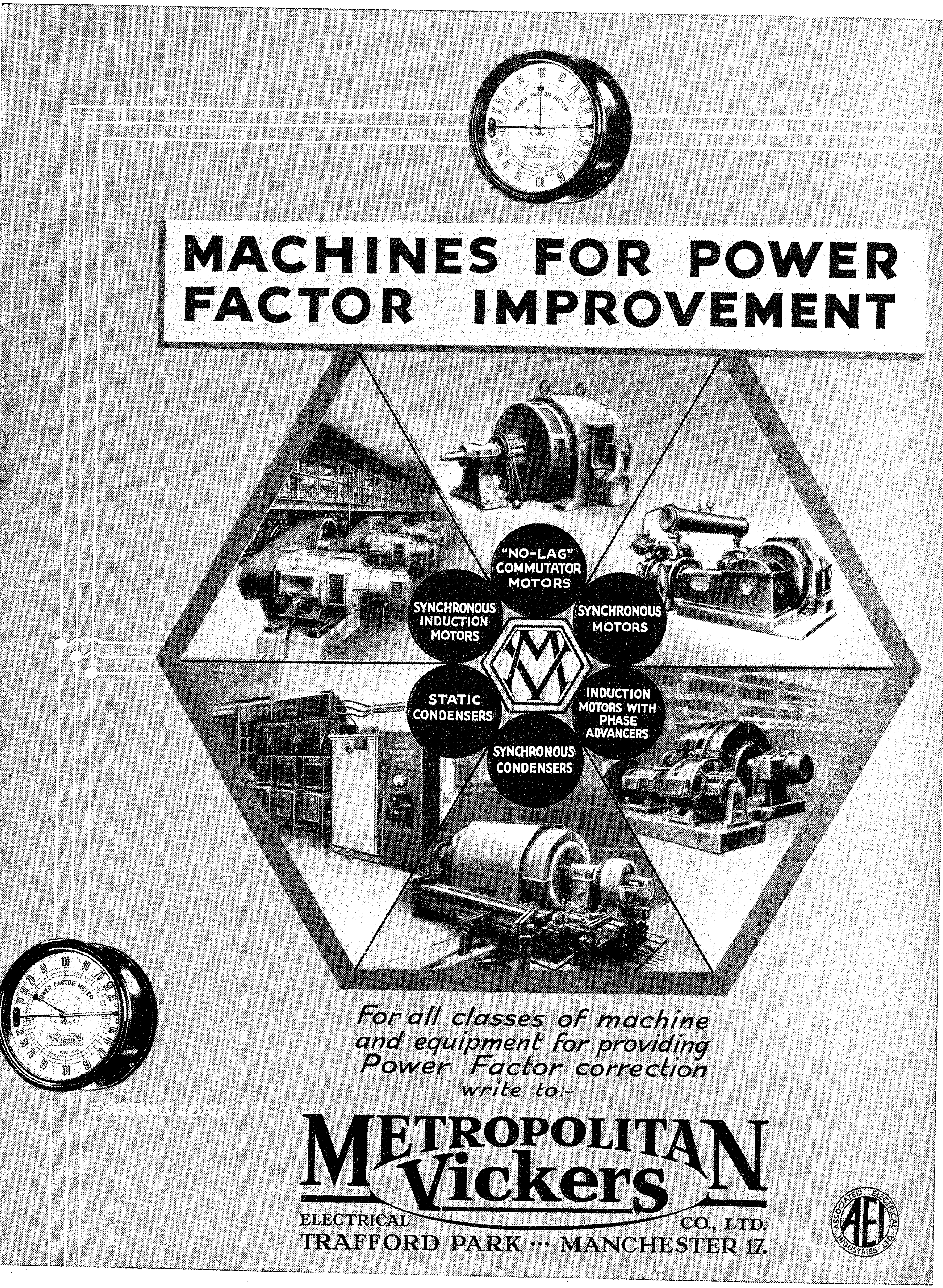

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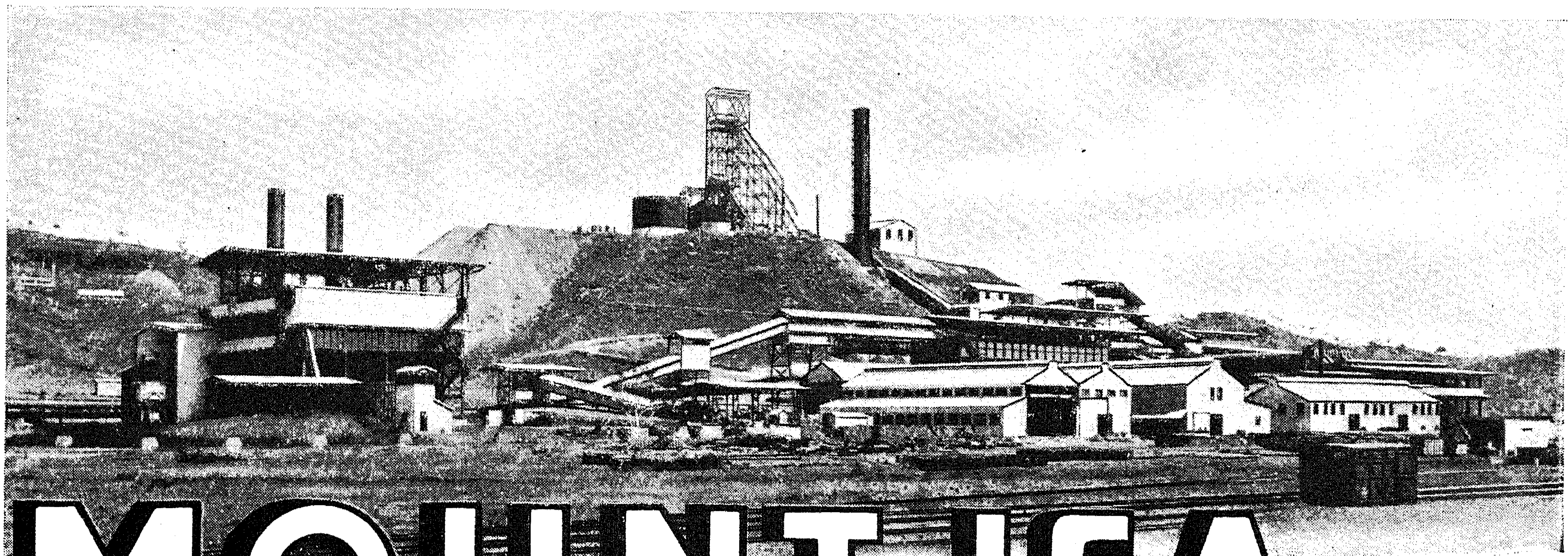

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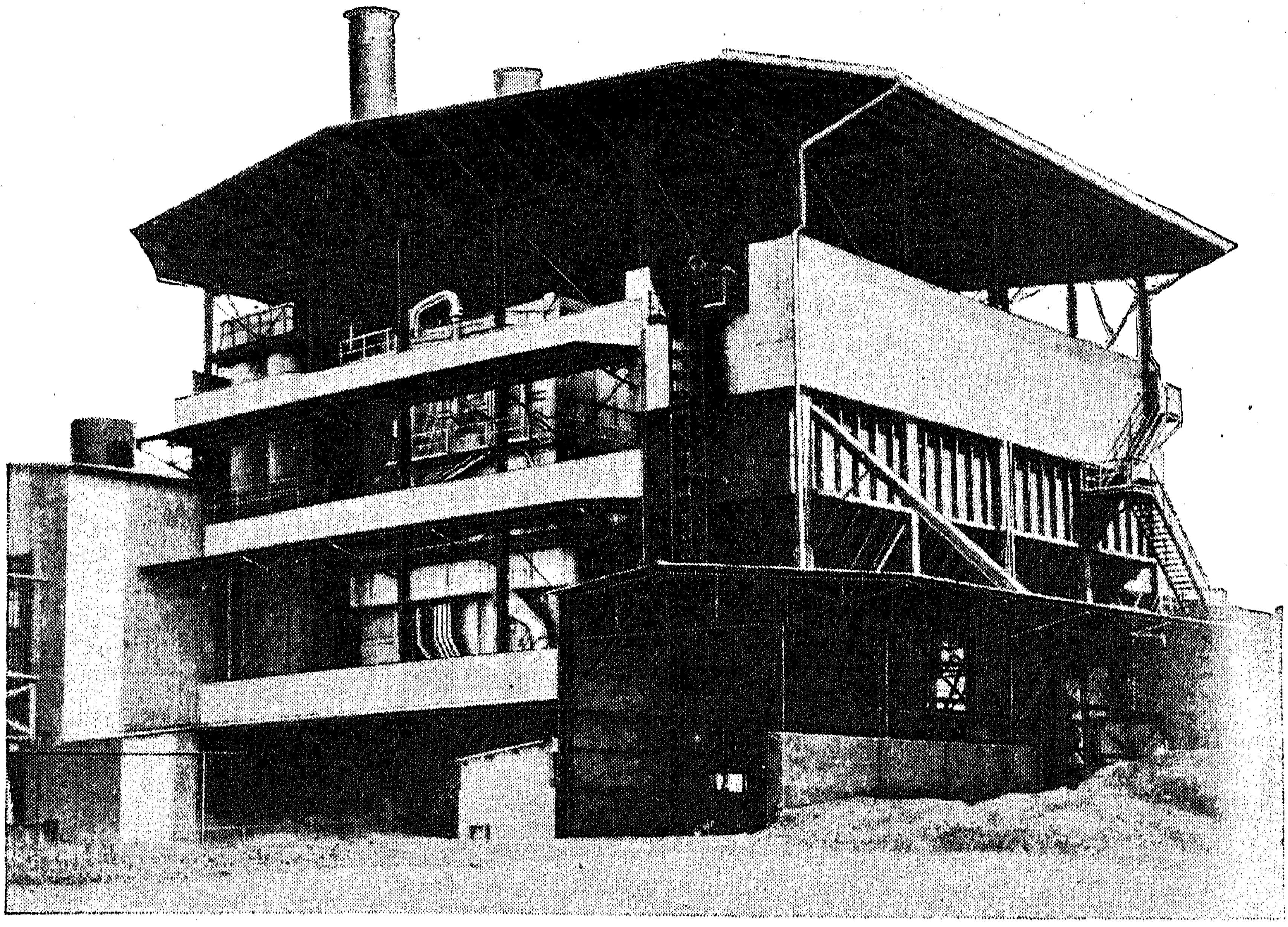

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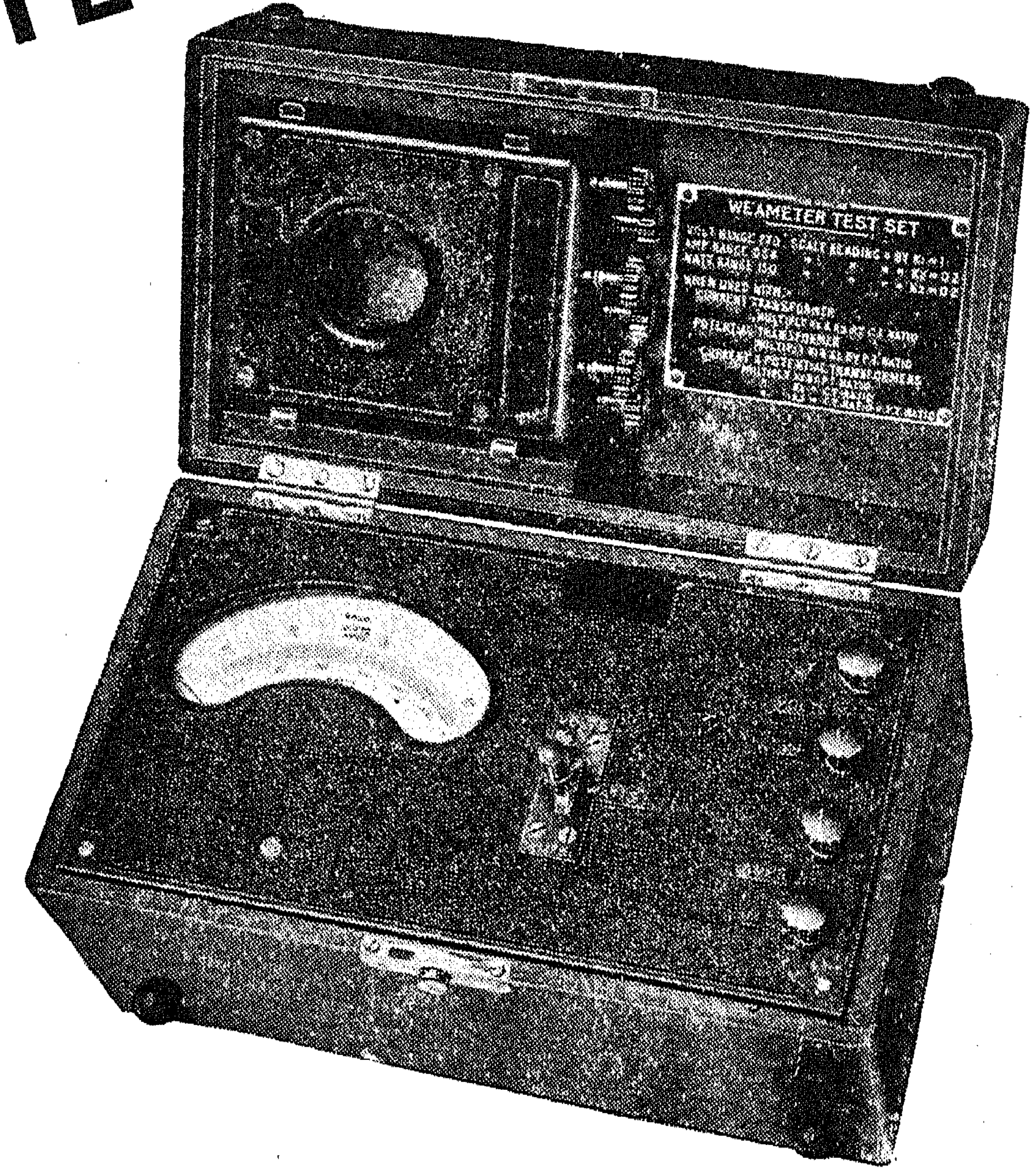

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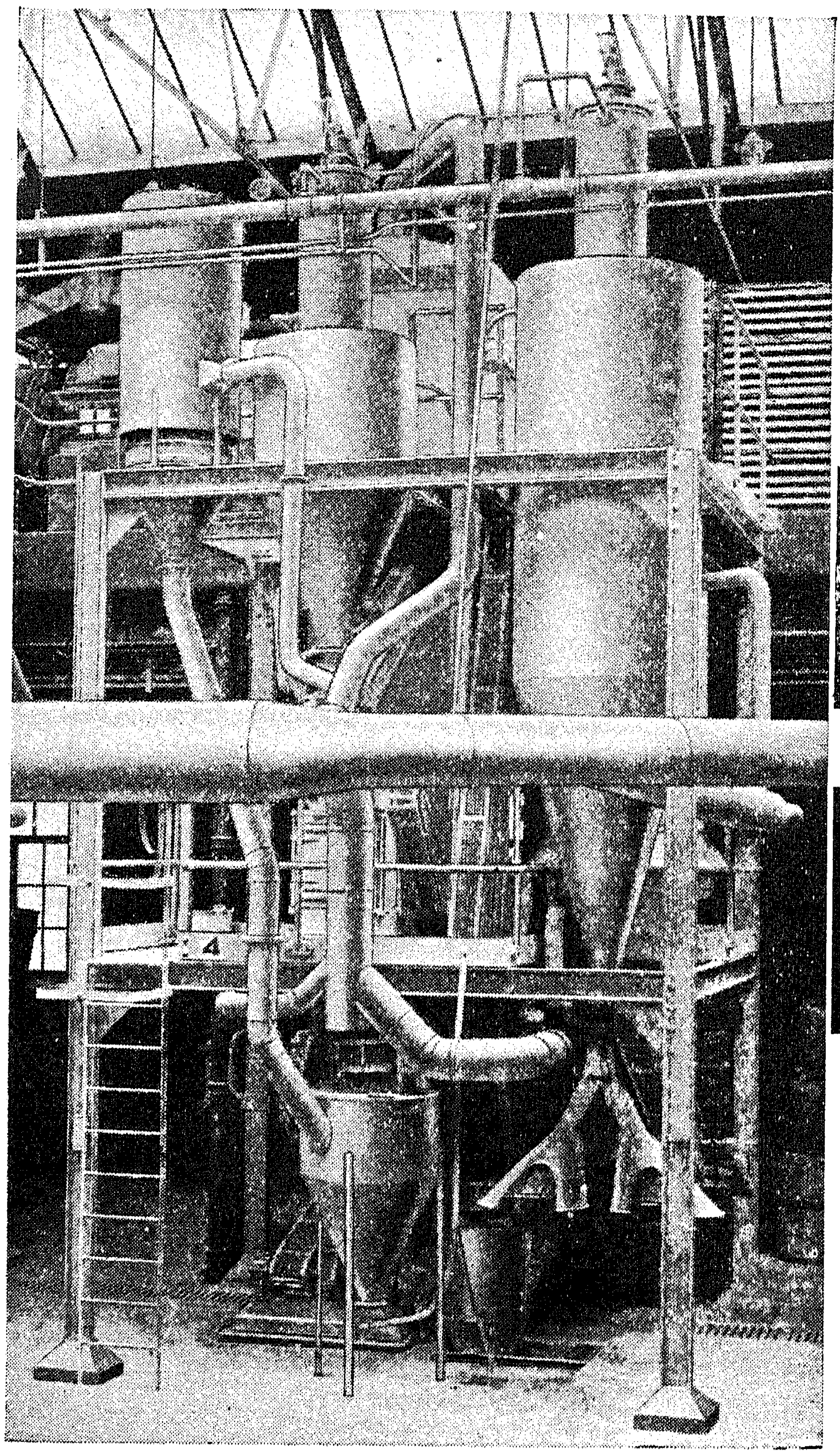

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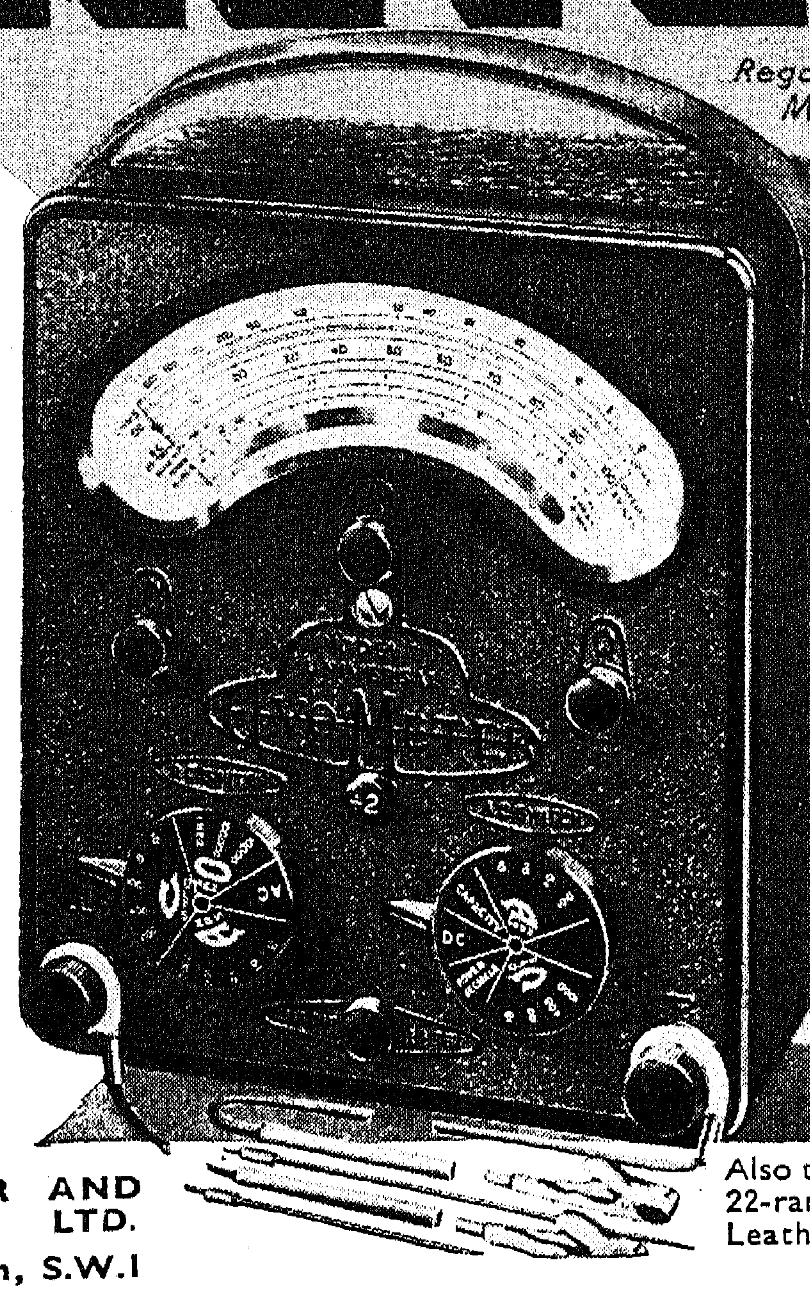

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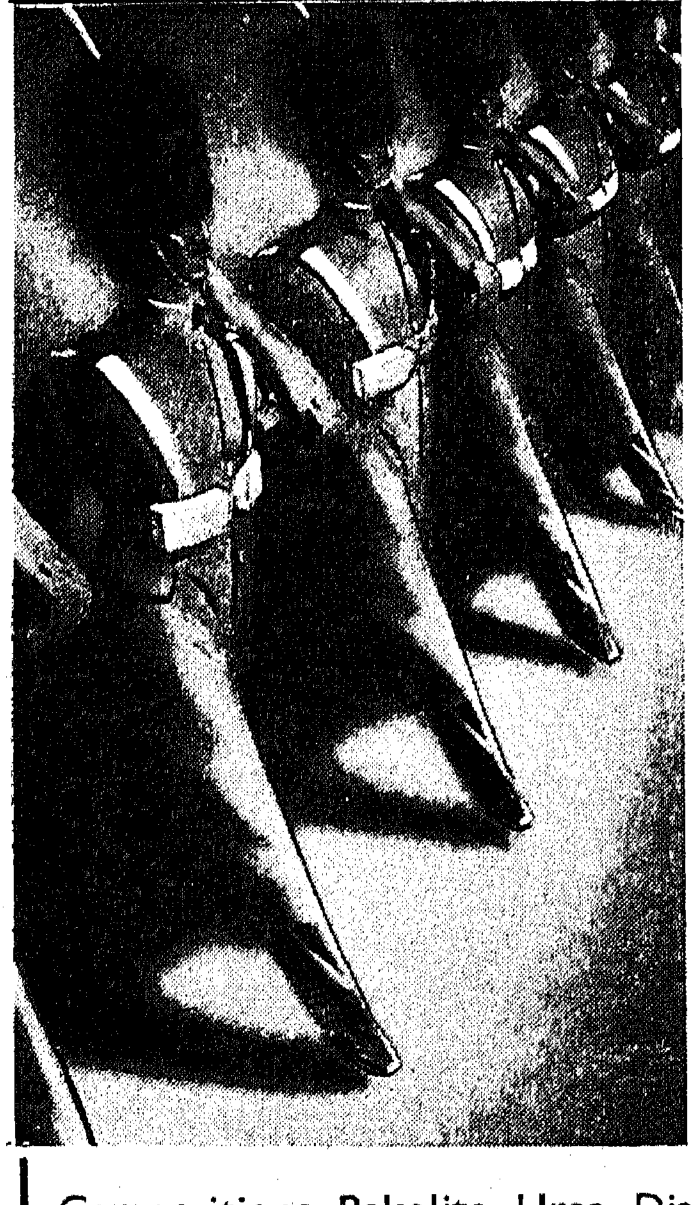

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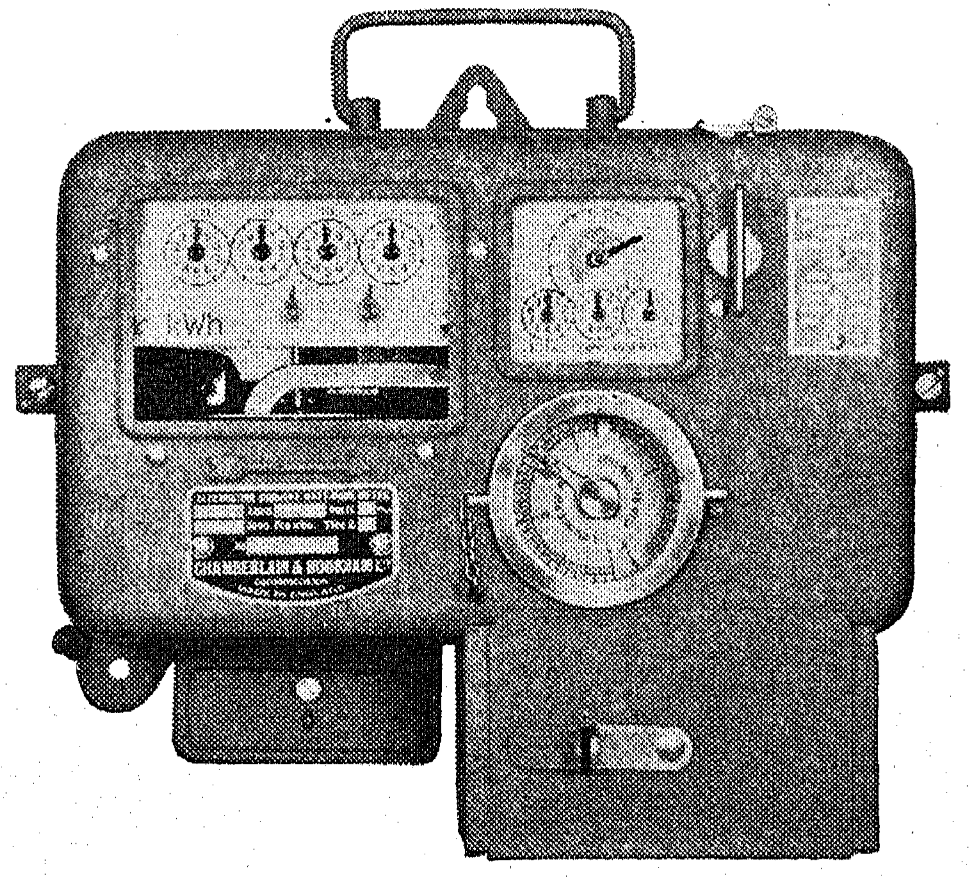

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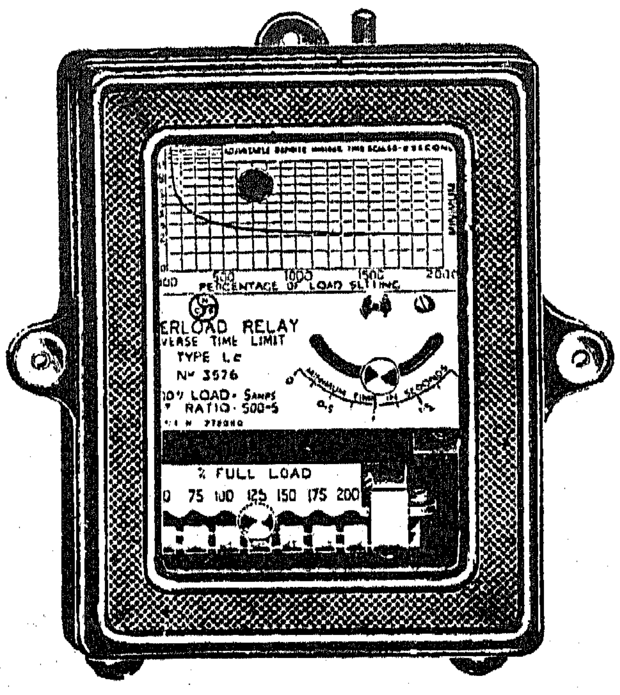

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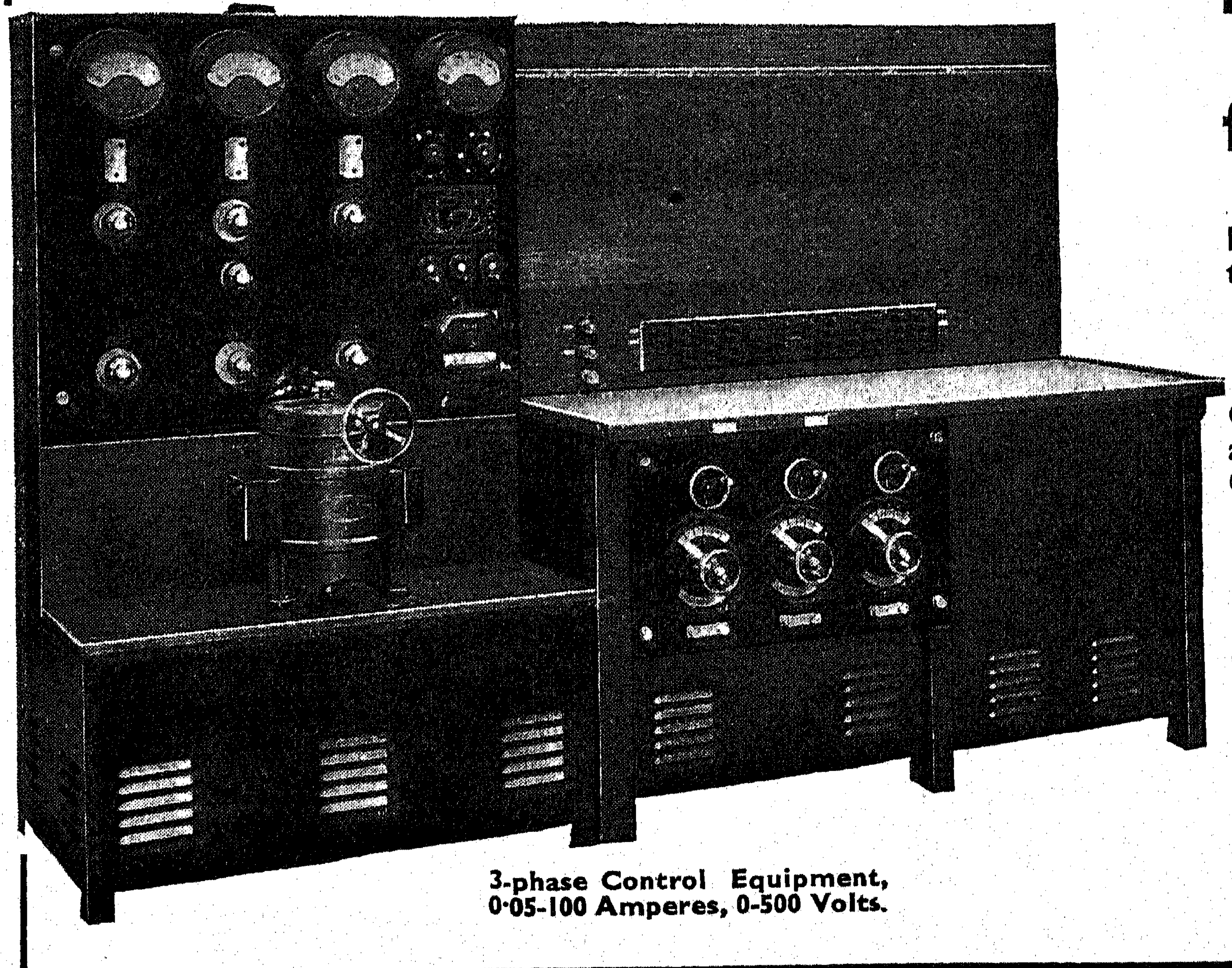

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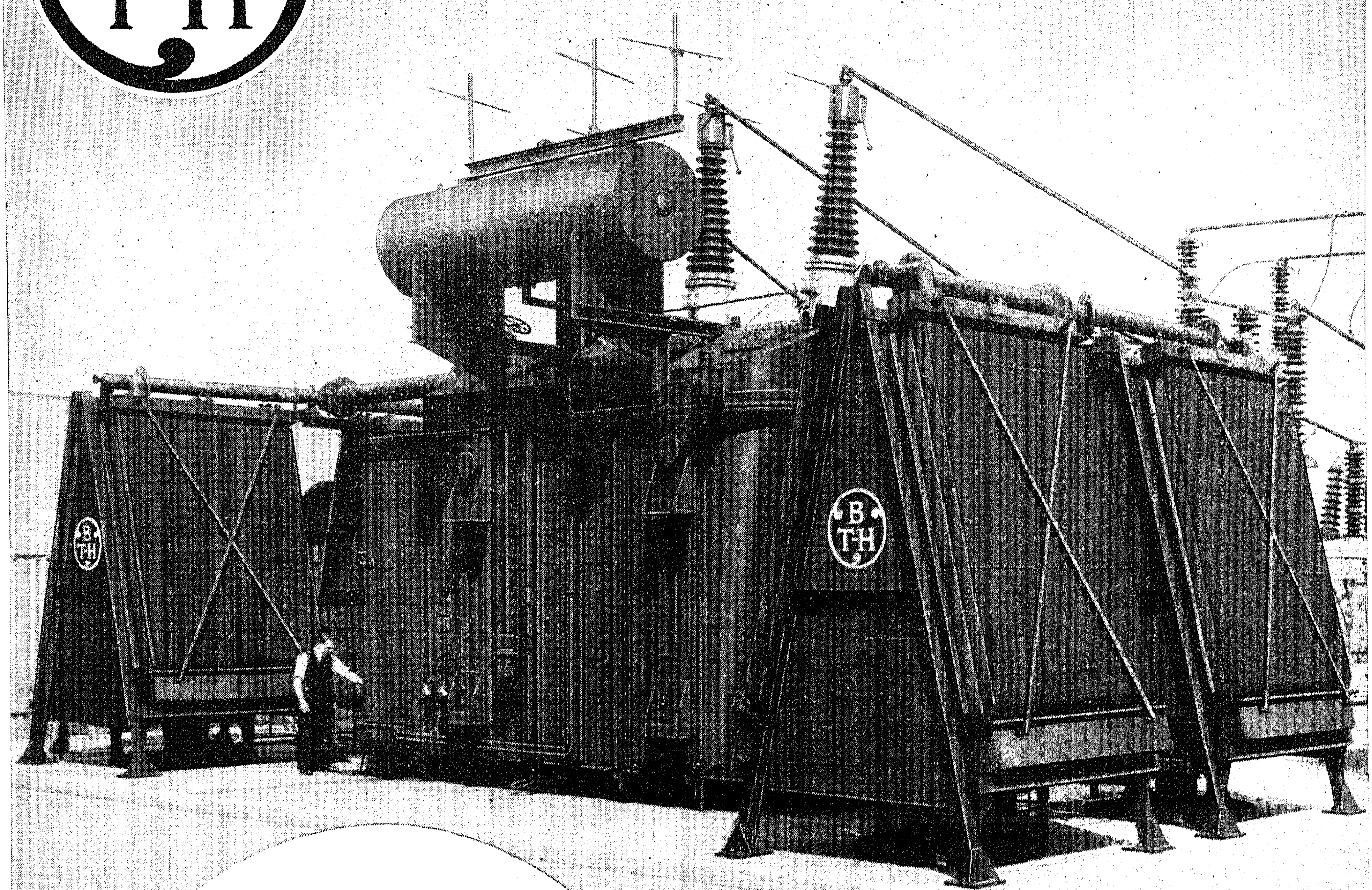

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